DESIGN AND R&D PROCESS OF AN AUTONOMOUS WATER SURFACE CLEANING VEHICLE

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ETHICAL DECLARATION

I hereby declare that I am the sole author of this thesis and that I have conducted my work in accordance with academic rules and ethical behaviour at every stage from the planning of the thesis to its defence. I confirm that I have cited all ideas, information and findings that are not specific to my study, as required by the code of ethical behaviour, and that all statements not cited are my own.

Oğul Görgülü
14.06.2023
Signature:

ABSTRACT

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Görgülü, Oğul

Master's Program in Design Studies

Advisor: Asst. Prof. Dr. Can ÖZCAN

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The Ports and marinas have transformed into destinations providing a wide range of services and events. This growth's accompanying expansion in services and activities could have a negative impact on the marine environment. Population density, urbanization, wastewater treatment, and sewage sludge all have a massive effect on this waste, hence it is crucial to cut back on plastic use and manufacture globally.80 percent of marine waste originates on land, and more rubbish is thrown there by the wind, the rain, or negligent people than it is in the seas and oceans. The majority of the waste in ports, marinas, and canals is dispersed by currents and efficiently reaches difficult-to-reach locations (between boats, under docks, etc.). The current marine waste disposal procedure relies on human intervention, yet these wastes can threaten human health and safety. For this reason, it is important to collect the waste at the closest point from the emission sources before the waste is dispersed in the sea. A significant outcome of this thesis will deliver practical insights for integrated coastal and marine management and demonstrate the usefulness of the Autonomous Water

Surface Cleaning Vessel to support the implementation of environmental goals. Additionally, the opportunities and challenges of these Autonomous Vessel technologies are discussed. The main objective of this research the design of an Autonomous Water Surface Cleaning Vessel that can detect and collect waste in water bodies.

Keywords: Autonomous vessel, Autonomous Water Surface Cleaning Vessel, Design method, Marine, Marine waste, monitoring.

ÖZET

OTONOM SU YÜZEYİ TEMİZLEME ARACI TASARIMI VE AR-GE SÜRECİ

Görgülü, Oğul

Tasarım Çalışmaları Yüksek Lisans Programı

Tez Danışmanı: Dr. Öğr. Üyesi Can ÖZCAN

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Limanlar ve marinalar, geniş bir hizmet ve etkinlik yelpazesi sunan destinasyonlara dönüşmüştür. Bu büyümeyle birlikte sağlanan hizmetlerin ve etkinliklerin genişlemesi, deniz çevresi üzerinde olumsuz bir etkiye sahip olabilir. Nüfus yoğunluğu, kentleşme, atık su arıtma ve kanalizasyon çamuru, bu atık üzerinde büyük bir etkiye sahiptir, bu nedenle küresel olarak plastik kullanımını ve üretimini azaltmak son derece önemlidir. Deniz atıklarının yüzde 80'i karadan kaynaklanmaktadır ve daha fazla çöp rüzgar, yağmur veya ihmalkar insanlar tarafından denizlere ve okyanuslara atılmaktadır. Limanlar, marinalar ve kanallardaki çöplerin çoğu akıntılar tarafından dağıtılır ve zor ulaşılan yerlere etkili bir şekilde ulaşır (tekne araları, iskele altları vb.). Mevcut deniz atığı bertaraf prosedürü, insan müdahalesine dayanır, ancak bu atıklar insan sağlığı ve güvenliğini tehdit edebilir. Bu nedenle, atıkların denize dağılmadan önce emisyon kaynaklarından en yakın noktada toplanması önemlidir. Bu tezin önemli bir sonucu, bütünleşik kıyı ve deniz yönetimi için pratik bilgiler sunacak ve Çevresel hedeflerin uygulanmasını desteklemek için Otomatik Su Yüzeyi Temizleme Aracının kullanışlılığını gösterecektir. Ayrıca, bu Otomatik Aracı teknolojilerinin fırsatları ve zorlukları tartışılmaktadır. Bu araştırmanın ana hedefi, su kütlelerindeki atıkları tespit edebilen ve toplayabilen bir Otomatik Su Yüzeyi Temizleme Aracının tasarımıdır.

Anahtar Kelimeler: Otonom gemi, Otonom Su Yüzeyi Temizleme Gemisi, Tasarım yöntemi, Deniz, Deniz atığı, İzleme..

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To all those who have been a part of this endeavor, thank you for believing in me and collaborating with me on a project that holds great promise. I am optimistic that this thesis marks the beginning of a larger vision, and I hope that our collective efforts will contribute positively to the advancement of knowledge in our chosen field.

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LIST OF ABBREVIATIONS

AL	Autonomy Levels
ARPA	Automatic Plotting Radars
AIS	Automatic Ship Identification System
AI	Artificial Intelligence
ARPA	Automatic Plotting Radars
ARS	Aerial Remote Sensing
ANS	The Autonomous Navigation System
COLREGs	International Regulations for Preventing Collisions at Sea
CAD	Computer Aided Drawing
CO	Collision Avoidance
ECDIS	Electronic Chart Display & Information System
EMS	Environmental Management System
EU	European Union
EEDI	The Energy Efficiency Design Index
IMO	International Maritime Organization
ICT	Information Communication Technology
LR	Lloyd's Register Group Limited
LOA	Level of Autonomy
MALPOL	Marine Pollution
MSFD	The Marine Strategy Framework Directive
ML	Machine Learning
MASS	Maritime Autonomous Surface Ships
MSDF	The Marine Strategy Framework Directive
GNC	Guidance, Navigation, and Control
GES	Good Environmental Status
GPS	Global Positioning System
GES	Good Environmental Status
RSE	Regulatory Scoping Exercise
RMS	Risk-Management System
RRF	Restoration Reporting Framework
SRS	Satellite Remote Sensing

SSD	Ship State Detection
USV	Unmanned Surface Vehicles
UUV	Unmanned Underwater Vehicles
UAV	Unmanned Aerial Vehicles
WWF	World Wide Fund
WTP	Wastewater Treatment

CHAPTER 1: INTRODUCTION

Water pollution is mainly caused by urbanization, industrialization, agriculture and the increase in human population observed in the last century and a half, and this increase in waste threatens the existence of life day by day (Goel, 2006). According to the "Goal 14: Life Below Water" report, Goal 14, one of the United Nations' Sustainable Development Goals (Goals, 2023) , ocean and marine life are under threat due to pollution. The prevention and reduction of all forms of marine waste from land-based activities, particularly marine waste and nutrient pollution, is crucial for sustainable development by the year 2025 (United Nations, 2003). Many international, municipal, and non-governmental groups have been concerned about environmental issues as a result of the growing human population and the climate crisis, particularly in recent years. The marine ecology is being irreparably harmed by plastic waste. In addition to that, plastic waste comes in a wide range of sizes, shapes, and chemical compositions. Plastics containing compressed air with high buoyancy (e.g. expanded polystyrene, intact bottles, buoys) disperse in many places by breaking waves and ocean turbulence and can mix up to tens or hundreds of meters. (Kukulka et al., 2012).

Much of this solid and liquid waste is swept away, turning our seas and oceans into garbage soup and sometimes coalescing to form floating piles of garbage. (Denchak, 2018). However, reducing and managing this pollution is crucial for a sustainable ecosystem. While marine technologies may have the potential to solve such problems, the vessels of the future may have the potential to manage this type of waste without human intervention. With Industry 4.0, which offers automation to all sectors, it is possible to automate the waste management process (Phirke et al., 2021). While plastic waste capture devices can help reduce the flow of plastic waste from freshwater, at-source management of plastic waste is also needed to ultimately clean up our oceans and waterways (Helinski et al., 2021) . Utilizing technological solutions to ensure water and waste management, an understanding of site conditions, community involvement, and a long-term maintenance plan are important for a sustainable marine environment. With the production boom in plastics production, the ability to remove it from the environment becomes increasingly difficult without an efficient waste management.

1.1. Problem Definition

The research objective of this project is to evaluate the currently available design process of the Autonomous Water Surface Cleaning Vessel and determine their strengths and weakness in order understand possibility of the vessel design.

The objectives of this thesis can, therefore, be broken down to several sub-objectives as listed below which are necessary steps for the process evaluation and design of an Autonomous Water Surface Cleaning Vessel:

1) Evaluate environmental problems in marine ecosystems.
2) Analyses potential solutions Autonomous Vessel technologies
3) Determine the appropriate design method
4) Analyze the prototype and enable implementation of automated design processes and improved test scope definition.
5) State recommendations for further work

1.2. Framework and Scope of the Thesis

The scope of this study is limited to the design of Autonomous Water Surface Cleaning Vessel, analysis of autonomous systems and their potential for use in marine environment, including rivers and other canals, lakes and reservoirs, and near-shore coastal waters such as ports, harbors and estuaries. To address the problem of marine waste floating on water, this project proposes the design of an autonomous water-cleaning vessel that can detect and collect waste in water bodies.

The design mythology consists of hull design to estimate hydrodynamic performance, 3d models printing, hardware component and preliminary evaluation of semi-autonomous capabilities. The paper represents the prototype-based model to evaluate object-based water surface waste capturing, path planning and collision avoidance.

It is planned as a smart water surface vehicle to automate the services of zero emission, solar powered, efficient, artificial intelligence supported, self-driving, autonomous surface vehicle. The autonomous vessel project was born from the idea of how and how it can promote the reallocation of urban infrastructure and the marine environment.

Compared to manned water surface cleaning vehicles, the Autonomous Water Surface Cleaning Vessel aims to perform services including cleaning the sea surface wastes, surface oil, and foam in shallow water locations. Develop an electric-powered solution that employs artificial intelligence (AI) to locate and collect garbage in shallow water locations inaccessible to manned vessel while also saving time and fuel and worker safety risks in vessel, lakes, canals, rivers, ponds, and port areas. It intends to provide a portable, lightweight, and small product service while building a garbage pickup robot.

It provides a service opportunity that allows autonomous or remote cleaning of surface wastes in a completely safe way in areas close to vessels in ports and marinas, in pontoon areas and in areas where it is difficult for the user to reach. Marine waste caused by the streams flowing into their marinas, a problem that marina managers face, is considered as a potential area of use for the Autonomous Water Surface Cleaning Vessel.

CHAPTER 2: COASTAL AND MARINE ENVIRONMENTAL MANAGEMENT

2.1. Overview of Marine Pollution

The global population is constantly increasing sharply, as it is estimated that 70% of the world's population will live in cities by 2050 (United Nations, 2018) . Therefore, this movement poses a threat to the environment, with challenges and opportunities for everyone, including people, companies, organizations, and governments, whose ultimate goal is to deliver a better quality of life for all. With the increase in the transportation ecosystem of private vehicles in big cities, urban mobility becomes more complex and difficult in the recent years (Ribeiro et al., 2021). With the increase in road traffic, situations such as congestion in transportation, environmental pollution, noise and traffic accidents, which directly affect the quality of urban transportation services and force access, bring many environmental problems in big cities.

The United Nations has established in its 2030 Agenda for Sustainable Development (Nations, 2015), under the name of Sustainable Cities and Communities, with 17 Sustainable Development Goals (Figure 1) covering cities and human settlements to be sustainable and safe. However, it makes cities critical to achieving a sustainable future for the world. Goal 14 and Goal 6 of the United Nations' Sustainable Development Goals (SDGs) are important for addressing marine pollution due to their focus on water resources and sustainable management.

Figure 1. United Nations Sustainable Development Goals (Source: Nations, 2023)

Goal 6, Clean Water and Sanitation, not only focuses on the provision of clean water and sanitation for all individuals but also holds relevance in addressing the issue of marine pollution. Marine pollution is frequently driven by contamination originating from land-based sources, such as industrial and agricultural activities, inadequate waste management systems, and insufficient wastewater treatment practices (Prata, 2018). Within the framework of Goal 6, the emphasis on clean water and sanitation encompasses the imperative to prevent water pollution, including pollution that ultimately finds its way into the oceans. By promoting the sustainable management of water resources, implementing effective wastewater treatment methods, and adopting pollution prevention measures, Goal 6 can make significant contributions to reducing the influx of pollutants into various water bodies, including rivers and coastal areas(Walker, 2021). Consequently, these efforts can help minimize the adverse impacts of such pollutants on marine ecosystems.

Goal 14 centers on the preservation and sustainable utilization of oceans and marine resources, encompassing the mitigation and prevention of marine pollution, particularly originating from land-based activities. The international community recognizes (Krause et al., 2021) the reduction of floating plastic debris as imperative for the sustainable utilization of oceans. The primary objective of Goal 14 is to avert and significantly diminish marine pollution, including marine debris and nutrient pollution, by the year 2030 (Borrelle et al., 2020). This goal holds great significance in combatting marine pollution due to its acknowledgement of the pivotal role that thriving marine ecosystems play in upholding biodiversity, livelihoods, and the overall well-being of the planet. By prioritizing Goal 14, concerted endeavors can be channeled towards the prevention and reduction of marine pollution, encompassing marine debris and nutrient pollution, which pose significant threats to marine ecosystems. Accomplishing Goal 14 would contribute to the safeguarding of marine biodiversity, the restoration of degraded habitats, and the preservation of marine species, thereby mitigating the detrimental consequences of pollution on marine ecosystems.

Collectively, the integration of Goal 14 and Goal 6 establishes an inclusive and holistic structure for tackling marine pollution. While Goal 14 concentrates explicitly on the preservation and sustainable utilization of marine resources, Goal 6 encompasses the wider scope of water quality enhancement and pollution mitigation. Through the prioritization of these goals, policy-makers, researchers, and involved parties can collaborate in the pursuit of sustainable approaches, enhanced waste management strategies, and efficacious pollution control measures. These concerted efforts are essential for the safeguarding of marine ecosystems, the promotion of biodiversity conservation, and the preservation of the well-being and vitality of both aquatic organisms and human populations reliant upon marine resources.

According to the Marine Strategy Framework Directive(Olenin et al., 2010), good environmental conditions in the seas were required for EU member countries to have effective management strategies. It was also emphasized by the Port Acceptance Facilities Directive that ports should have the physical infrastructure necessary to support this framework plan (Onay et al., 2021). The Marine Strategy Framework Directive (MSFD) was developed by the European Commission to address the excessive pressures and demands on marine resources and promote the protection and sustainable use of marine ecosystems (Olenin et al., 2010) . The MSFD serves as the environmental pillar of the Integrated Maritime Policy for the European Union, aiming for sustainable growth of maritime sectors which sets a framework for EU Member States to achieve or maintain Good Environmental Status (GES) for the marine environment, encompassing the management of human activities and their impact on the environment (Schlacke et al., 2011).

Implementing the Marine Strategy Framework Directive poses challenges for EU Member States in determining GES for marine ecosystems. GES can have different interpretations in different marine regions or subregions. The MSFD requires a comprehensive assessment of the impacts of human activities on the marine environment, including marine litter. Multiple indicators are necessary to assess GES related to different compartments of the marine environment and aspects of litter pollution. Metrics for evaluating the biological impacts of litter are lacking, so proxies such as the amount of litter on the sea floor or beaches can be used as indicators of progress towards GES (Galgani et al., 2013).

The implementation process of the MSFD involves six procedural steps for Member States, including initial assessment, determination of GES, establishment of environmental targets and indicators, development of a monitoring program, formulation of a program of measures, and the entry into operation of the measures (Galgani et al., 2013). These steps ensure consistent criteria, methodologies, and harmonization across the EU in assessing GES.

2.1.1. Causes of Marine Pollution

Marine pollution is a significant environmental issue that threatens the health and survival of marine ecosystems, as well as human health and well-being. The causes of marine pollution are complex and varied, but can be broadly categorized as land-based sources of pollution and ocean-based sources of pollution. Land-based sources of pollution include agricultural runoff, urban runoff, industrial discharge, and improper waste management. Ocean-based sources of pollution include shipping, oil and gas exploration, aquaculture, tourism, and marine litter. Marine litter, including plastics, fishing gear, and other debris, is a significant source of pollution in the oceans. The problem of plastic waste is spreading rapidly and is projected to triple by 2040, with the Mediterranean region producing the majority of the world's plastic waste. The mitigation of marine pollution requires a multifaceted approach involving regulations, sustainable practices, and cleanup efforts.

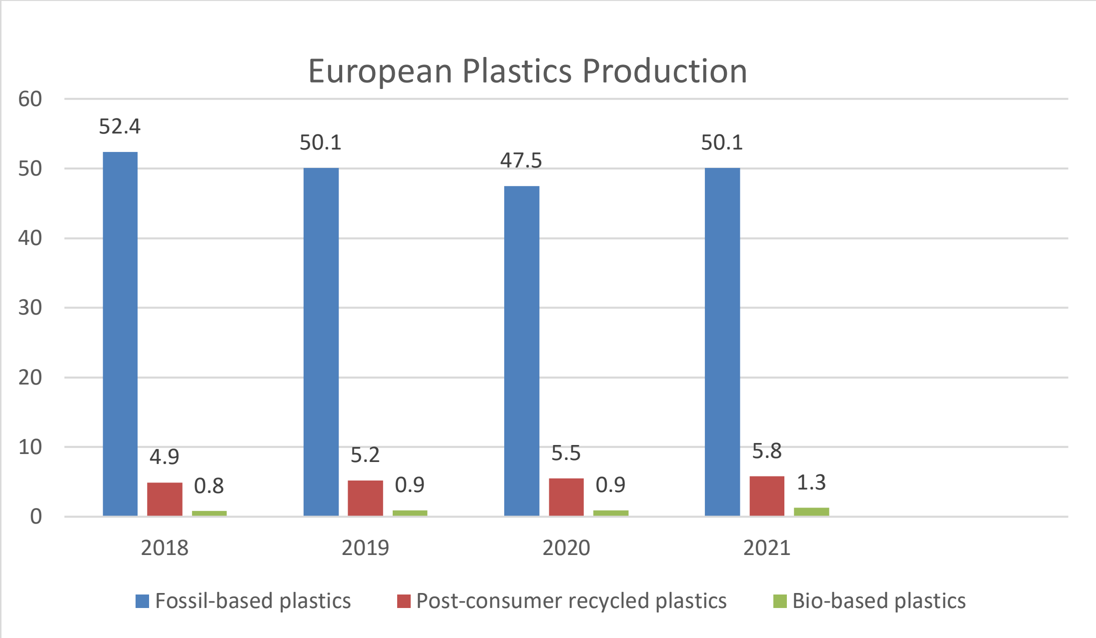
An overwhelming ranging from 45% to 95% of the waste littering the Mediterranean's open waters, seabed, and coasts is comprised of plastic (UNEP - UN Environment Programme, 2015). The primary sources of this pollution are Turkey and Spain, followed by Italy, Egypt, and France (Table 1). Mediterranean, posing a substantial threat to marine life where large plastic debris often results in injury, suffocation, and frequent fatality to marine creatures, including protected or endangered species. However, the main menace in the Mediterranean is presented by smaller, insidious microplastics, whose concentration surpasses that of the plastic island in The Northern Pacific Ocean by four times (Alessi, 2018) . These particles, now integrated into the food chain, pose escalating risks to numerous animal species and human health (Andrady, 2011).

Table 1. Coastal Population and Waste/plastic generation in 2010 in the Mediterranean countries (Source: Boucher and Billard, 2020)

Country	Coastal population[1]	Waste generation rate [kg/person/day] [2]	% Plastic in waste stream[2]	% Inadequately managed waste[3]	Waste generation [kg/day]	Plastic waste generation [kg/day]	Inadequately managed plastic waste [kg/day][4]	Plastic waste littered [kg/day][4]
Albania	2 530 533	0,77	9	45	1 948 510	174 392	77 897	3 488
Algeria	16 556 580	1,2	12	58	19 867 896	2 374 214	1 378 693	47 484
Bosnia/Herzegovina	585 582	1,2	12	40	702 698	83 972	33 813	1 679
Croatia	1 602 782	2,1	12	9	3 365 842	402 218	37 053	8 044
Cyprus	840 556	2,07	12	0	1 739 951	207 924	831	4 158
Egypt	21 750 943	1,37	13	67	29 798 792	3 858 944	2 572 170	77 179
France	17 287 280	1,92	10	0	33 191 578	3 302 562	0	66 051
Greece	9 794 702	2	10	0	19 589 404	1 949 146	0	38 983
Israel	6 677 810	2,12	14	1	14 156 957	1 974 896	12 577	39 498
Italy	33 822 532	2,23	6	0	75 424 246	4 487 743	0	89 755
Lebanon	3 890 871	1,18	8	34	4 591 228	365 003	123 700	7 300
Libya	4 050 128	1,2	12	23	4 860 154	580 788	132 985	11 616
Malta	404 707	1,78	12	6	720 378	86 085	5 456	1 722
Monaco	34 050	2,1	12	0	71 505	8 545	0	171
Montenegro	260 336	1,2	12	30	312 403	37 332	11 353	747
Morocco	17 303 431	1,46	5	66	25 263 009	1 250 519	824 650	25 010
Gaza	3 045 258	0,79	8	6	2 405 754	191 257	11 515	3 825
Slovenia	336 594	1,21	12	1	407 279	48 670	550	973
Spain	22 771 488	2,13	13	0	48 503 269	6 281 173	0	125 623
Syria	3 621 997	1,37	13	65	4 962 136	642 597	419 763	12 852
Tunisia	7 274 973	1,2	12	60	8 729 968	1 043 231	621 077	20 865
Turkey	34 042 862	1,77	12	16	60 255 866	7 200 576	1 187 323	144 012
Total/mean	208 519 478	2	11	23	360 939 138	36 560 188	7 451 413	731 036

Plastic, a synthetic substance primarily derived from petroleum and other fossil materials, is a robust material widely used for its durability. However, this durability also renders plastic hazardous as most types are not biodegradable and persistently contaminate the environment over centuries. The prevalent plastic pollution in the Mediterranean is primarily attributable to many countries' (Table 1) delays and failures in implementing effective plastic waste management. Of the 57.2 million of plastic waste generated annually in Europe in 2021 (Table 2), only one-third is recycled (Plastic Europe, 2022). Plastic pollution detrimentally impacts key Mediterranean economic sectors, notably fisheries and tourism. Potential reductions in tourist numbers and associated job losses due to polluted beaches are also a concern.

Table 2. European plastics production (Source: Plastic Europe, 2022)



2.1.1.1 Land-based sources of pollution

Land-based sources of pollution are one of the primary causes of marine pollution, and they are responsible for a wide range of pollutants entering the marine environment. One of the most significant sources of land-based pollution is agricultural runoff which a study conducted by Jackson (Vogel et al., 2019) found that agricultural runoff was responsible for up to 90% of nitrogen and phosphorus pollution in some coastal areas. This type of pollution can lead to harmful algal blooms, oxygen depletion, and overall degradation of water quality. In addition to fact that, pesticides and herbicides used in agriculture can also enter the marine environment, which can have negative impacts on marine ecosystems (Oral, 2013).

Another major contributor to land-based pollution is urban runoff. Urban runoff occurs when rainwater flows over impervious surfaces, such as concrete and asphalt, and picks up pollutants such as oil, grease, heavy metals, and chemicals. This polluted water then enters streams, rivers, and eventually, the ocean. A study by Zhang (Qian et al., 2015) found that urban runoff was responsible for high levels of metal pollution in coastal areas of China, which negatively impacted the health of fish and other marine organisms. Industrial activities are also a significant contributor to land-based pollution. Industrial discharge can release heavy metals, oil, chemicals, and other pollutants into the marine environment. According to Moussa (Hegab, Mahmoud H., Ahmed, Nasr M., Kadry, Shadia M., ElSayed, Radwa A. and Goher, 2020) found that industrial discharge was responsible for high levels of pollution in coastal areas of Egypt, which negatively impacted the health of marine organisms and caused economic losses for the fishing industry.

When waste is not disposed of properly, it can end up in rivers and eventually the ocean. This type of pollution can harm marine life, damage ecosystems, and negatively impact the tourism industry. Land-based pollution sources are a principal cause of marine pollution, exerting a significant influence on the health of marine ecosystems and the economic welfare of communities residing in the coastal areas. Thus, it is imperative to implement various measures to curtail land-based pollution, which can include the adoption of improved agricultural techniques, enhanced management of stormwater, conscientious industrial practices, and efficient waste management.

2.1.1.2 Ocean-based sources of pollution

Marine pollution is one of the most significant environmental problems facing the world today. It poses a serious threat to the health and survival of marine ecosystems, as well as to human health and well-being. One of the leading causes of marine pollution is ocean-based source pollution, which includes a wide range of human activities that contribute to the release of pollutants into the marine environment (Derraik, 2002). Ocean-based source pollution is caused by various human activities such as shipping, oil and gas exploration, aquaculture, tourism, and marine litter. Shipping is one of the most significant sources of ocean-based pollution due to the release of pollutants from ship operations, including oil spills, ballast water discharge, and air pollution(Corbett et al., 2007). Oil and gas exploration also contribute to marine pollution through accidental oil spills, leakage from oil rigs, and drilling mud discharge. Aquaculture operations can also release pollutants such as fish feed, chemicals, and waste into the marine environment (Boyd and McNevin, 2014). The tourism industry contributes to pollution through sewage discharge, littering, and disturbance of natural habitats. Marine litter, which includes plastics, fishing gear, and other debris, is a major source of pollution in the oceans. Ocean-based source pollution is a significant threat to the health and well-being of marine ecosystems and human society. The causes and impacts of marine pollution are complex and wide-ranging, and therefore require a multifaceted approach to mitigation. Regulations, sustainable practices, and cleanup efforts are all essential components of reducing ocean-based source pollution. It is crucial that governments, industries, and individuals take responsibility for their actions and work together to protect the health and integrity of the marine environment (Ghosha et al., 2022).

2.1.1.3 Marine waste and plastic pollution

The second-largest producer of plastics after China, Europe yearly releases into the ocean between 70.000 and 130.000 tons of microplastics and between 150.000 and 500.000 tons of macro plastics, endangering both human and animal health (Alessi, 2018). Current consumption of plastic is progressing rapidly, particularly around the Mediterranean, as it reaches the oceans and seas and waste is expected to increase further (Lebreton and Andrady, 2019). The amount of plastic waste is anticipated to triple by 2040, with the Mediterranean region producing the majority of the world's plastic waste (Trusts, 2020). The projected cost of the harm to the aforementioned industries, including the expense of clearing up these wastes, is $13 billion (Alessi, 2018).

Plastic is a synthetic substance made of carbon that is obtained from fossil fuels like petroleum. Plastics are divided into 3 groups according to their parts and lengths as macro, micro and nano plastics. Due to their physical size, micro and nano plastics pose a risk to living things in marine and coastal ecosystems (M. B. Tekman, B. A. Walther, C. Peter, L. Gutow, 2022). Plastics discharged into the environment won't biodegrade since they are strong materials, and they last for hundreds or even thousands of years. Plastics enter the seas directly and indirectly. While direct mixing is caused by garbage left on beaches and plastic products released into the sea during fishing or transportation activities at sea, indirect mixing is the transport of plastic waste to the seas by various means, such as wind or river currents, because it is not properly managed and caused by activities on land. The problem of plastic waste is spreading exponentially from the poles to the most isolated islands, from the sea surface to the deepest ocean trench, as a result of global currents and winds, plastics on the water's surface, and garbage islands created by the oceans.

2.1.2. Impacts of Marine Pollution

Marine pollution, particularly caused by litter, has diverse impacts on marine life at various levels of organization. The severity of these impacts depends on factors such as the specific target species or population, environmental conditions, and geographical location (UNEP - UN Environment Programme, 2015). In addition to that, they include damage to marine ecosystems, loss of biodiversity, human health impacts, economic impacts, and social impacts. Waste can have ecological implications by disrupting marine ecosystems. Furthermore, the tourism and fishing industries, vital for coastal communities, can be adversely affected by litter pollution (Qian et al., 2015). Moreover, marine litter poses risks to human health and safety.

Marine pollution can harm marine organisms by causing physical harm or altering their habitat, leading to the loss of biodiversity. Pollutants can also enter the food chain and accumulate in the tissues of fish and other marine animals, posing a risk to human health. Economic impacts of ocean-based pollution include loss of fisheries, tourism revenue, and damage to shipping infrastructure. Finally, social impacts include the loss of cultural heritage, reduced recreational opportunities, and public health concerns.

2.1.2.1. Effects on Marine Ecosystems

Marine ecosystems are an integral part of our planet's biodiversity, providing us with numerous ecological, social, and economic benefits. However, pollution has become a major threat to these vital ecosystems, disrupting their delicate balance and causing widespread damage. Marine pollution is caused by a variety of sources, including agricultural runoff, industrial waste, and sewage discharge, among others. These pollutants can have a range of effects on marine ecosystems, including changes in water quality, decreased oxygen levels, and the accumulation of toxins.

Another study (Desforges et al., 2016) show that pollution can impact the behavior and physiology of marine mammals. The study found that pollutants such as PCBs and mercury can disrupt the endocrine system of marine mammals, leading to changes in their reproductive behavior and immune function. Additionally, pollutants can accumulate in the tissues of marine mammals, leading to long-term health effects and even death.

To mitigate the devastating impact of pollution on marine ecosystems, a comprehensive approach is needed. This approach should include measures such as the implementation of regulations to limit pollution sources, the adoption of sustainable practices, and the undertaking of cleanup efforts. It is imperative that governments, industries, and individuals take responsibility for their actions and work together to protect the health and integrity of our planet's marine ecosystems.

Marine ecosystems provide numerous benefits to humans, including food, carbon storage, waste detoxification, and cultural and recreational opportunities (Worm et al., 2006)(Liquete et al., 2013). However, the increasing amount of plastic pollution in the marine environment is threatening these ecosystem services and causing negative impacts on marine life. Despite the increase in research on plastic pollution in recent years, there is still a poor understanding of the holistic effects of marine plastic and its impact on ecosystem services and human wellbeing (Beaumont et al., 2019).

A new study has taken a three-step pluralistic approach (Figure 2) to synthesize available research into a global assessment of the ecological, ecosystem service, social, and economic impacts of marine plastic.

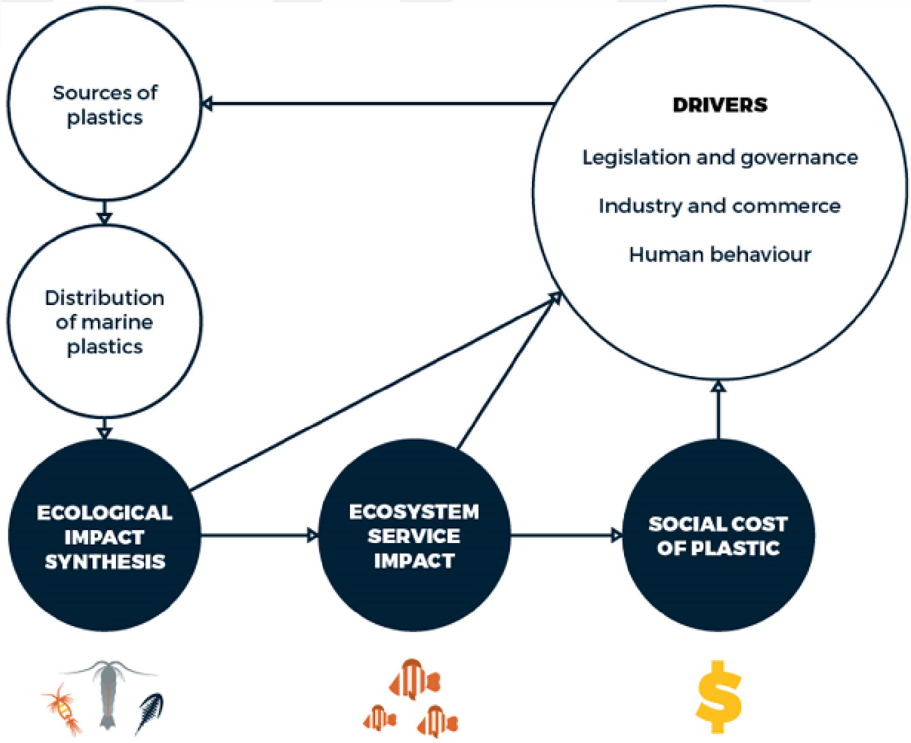


Figure 2. Conceptual diagram which describes the three steps approach to assess the societal impacts of marine plastic pollution (Source: Beaumont et al., 2019)

The results of this study show that all ecosystem services are impacted to some extent by the presence of marine plastic, and three critical ecosystem services are negatively impacted, including food provision, carbon storage, and coastal protection (Beaumont et al., 2019). Marine plastic has the capacity to accumulate in marine animals, leading to sub-lethal harm, lethal harm, and reduced reproductive success (Teuten et al., 2009). This can have population-level impacts on fish, shellfish, and their prey. Although the health risks of marine plastic for humans are still not well understood, existing literature suggests that the risks are minimal. However, there is a perceived risk of contamination of seafood with microplastic, which could be detrimental to fisheries.

Marine debris has various impacts on the environment and society that people's activities increase the amount of natural material entering the ocean, and also introduce artificial materials that pose new threats to the environment. Plastic debris is of great concern, especially microplastics and nano plastics, as they can enter the food web and accumulate in organisms, causing physical injury, starvation, and death (Provencher et al., 2019). Derelict fishing gear is one of the most abundant and conspicuous types of marine debris, and fishing nets cause significant damage to coral reef ecosystems and kill marine animals (Maximenko et al., 2019). In addition to that, large debris, such as shipping containers, can also pose a threat to maritime activity.

2.1.2.2.Human Health Impacts

Water pollution occurs when undesired substances enter water, resulting in alterations to water quality and detrimental effects on the environment and human well-being. Water is a crucial natural resource utilized for drinking and various developmental purposes in our lives. Ensuring safe drinking water is essential for human health; however, the World Health Organization (WHO) reports that 80% of diseases are transmitted through water (United Nations, 2003). Major sources of water pollution comprise domestic sewage, industrial waste, population growth, pesticides and fertilizers, plastics, and urbanization. Domestic sewage, industrialization, population growth, pesticides, and fertilizers are the primary contributors to water pollution (Haseena et al., 2017) . Specifically, domestic sewage contains toxic substances, solid waste, plastic debris, and bacterial contaminants, making it the primary cause of water pollution. The rising population results in increased generation of solid waste, which finds its way into rivers, and human excreta also contaminate water. Hence, it is advisable to regularly monitor water quality to prevent its detrimental impact on human health (Haseena et al., 2017).

The existence of marine litter, both stranded and floating, presents various health hazards to the public. Larger debris items like glass, syringes, and medical waste have the potential to harm individuals visiting beaches. In certain UK coastal areas, injuries caused by needles account for approximately 4% of reported incidents (UNEP - UN Environment Programme, 2015). However, assessing the full extent of harm is challenging due to many unreported incidents, and measures such as cleaning, regulation, and public awareness campaigns can help mitigate risks associated with litter.

2.1.2.3.Economic Impacts

The ecosystem service analysis found that (Beaumont et al., 2019) plastic has a substantial negative impact on experiential recreation, with litter on the shore leading to economic costs, direct consequences on physical and mental health, and detrimental effects on mood and mental wellbeing . It is clear that the impact of marine plastic pollution on ecosystem services is a major issue that needs to be addressed to protect marine life and ensure the sustainability of human activities that rely on these ecosystems.

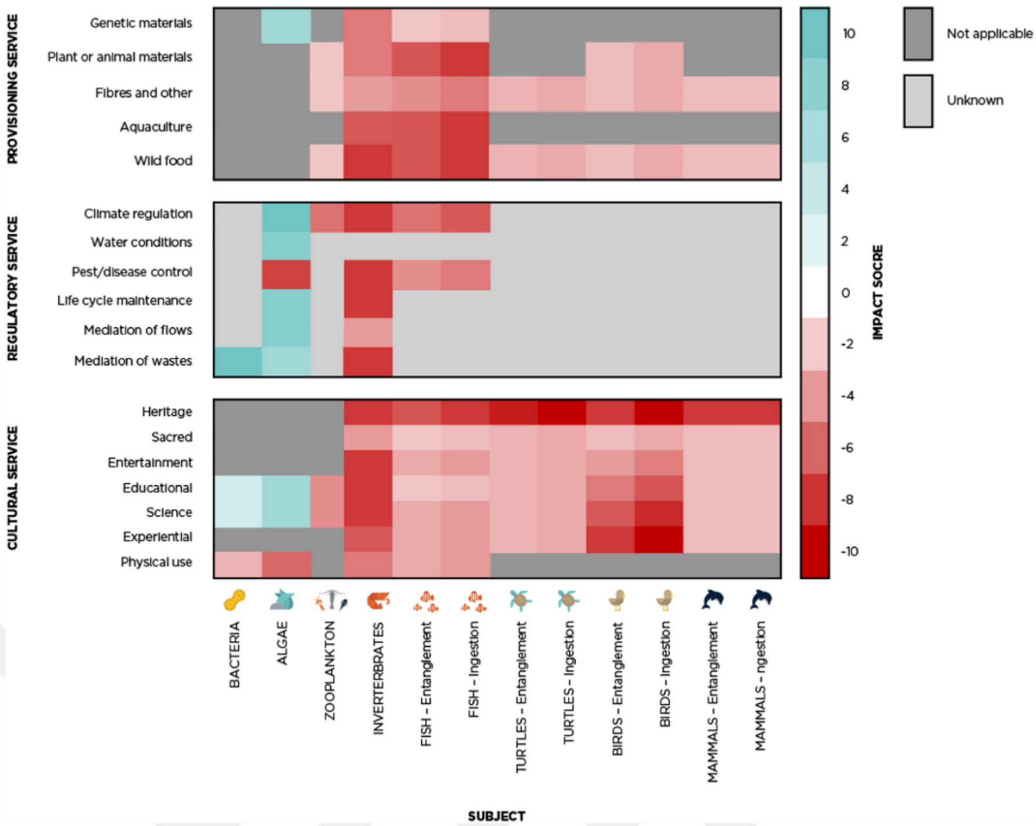


Figure 3. Ecosystem service impacts of marine plastic (Source: Beaumont et al., 2019)

Estimating the economic impact of marine plastic pollution on natural capital, which represents the world's reserves of natural assets, has been done based on available studies. While it is currently challenging to precisely measure the decline in annual delivery of ecosystem services due to marine plastic, (Figure 3) provides evidence of significant adverse effects on nearly all global ecosystem services. A conservative approximation suggests that the presence of marine plastic in the oceans in 2011 resulted in a 1-5% reduction in the delivery of marine ecosystem services, leading to an annual loss of $500-$2500 billion in the value of benefits derived from these services (Beaumont et al., 2019). It should be noted that this estimate represents the minimum economic cost of marine plastic and does not encompass broader social and economic costs, such as impacts on tourism, transportation, fisheries, and human health. Furthermore, plastic emissions, accumulation, and the resulting ecological harm will vary across different locations, and the cost associated with each tons of plastic will depend on its size, type, emission location, movement, accumulation, and the existing amount in the ecosystem (Beaumont et al., 2019) .

Therefore, the cost of each tons of marine plastic is likely to differ from the average, as plastic does not disperse uniformly. It is possible that the damage cost of each additional tons will increase, highlighting the need for further research to understand the marginal damage cost of additional marine plastic entering the oceans in order to calculate future total costs. Finally, plastic undergoes various transformations from macro to micro forms, with the accumulation and release of toxins and biological material, and it would be ideal to incorporate these changes when assigning a cost per tons value to plastic.

2.1.2.4.Social Impacts

The adverse impact of marine plastic on charismatic species can lead to a decline in human wellbeing due to the significant cultural and emotional value associated with these species. Additionally, the presence of plastic has the potential to cause substantial ecological changes in marine systems, which may result in unpredictable secondary consequences for society. Plastic serves as a stressor that can interact with other environmental stressors, leading to more extensive damage. The perception of marine plastic pollution by the public and the factors that influence public concern regarding this issue have been explored to a limited extent. A survey conducted by Eurobarometer in 2014 revealed that a majority of individuals residing in EU member states believed that additional initiatives were necessary to reduce the presence of plastic waste in the environment (Eurobarometer, 2014). However, research specifically focused on public perception of marine plastic pollution remains limited. Various factors, including demographics, coastal access and experience, and psychological factors, can predict concerns and beliefs related to plastic pollution (Hartley et al., 2018). Women, individuals with higher levels of education, and older adults are more likely to exhibit greater environmental concern. Moreover, political orientation has been associated with perceptions of environmental issues, with those leaning towards the political left tending to be more concerned (Davison et al., 2021). Theoretical assumptions suggest that contact with the marine environment may heighten exposure to and concerns about marine plastic pollution.

2.2. Marine Environmental Pollution in Turkey

According to the Turkey Maritime Sector Report 2021 (SHIPPING, 2021) , Turkey ranked 4th in the European ranking in 2019 (Figure 4) in the number of tourists by country, with 51.2 million tourists, and ranked 6th in the world in terms of the number of tourists by country. Most of the marine tourism operates in the Mediterranean region. With more than 200 million tourists visiting the Mediterranean each year, marine tourism in Turkey is expanding its capacity on a global scale (Coll et al., 2010). As a result, there is a 40% increase in marine waste throughout the summer period. Turkey has the longest coastline in Europe with a length of over 8,333 km, and is threatened by marine waste and its coastal ecology because it is the only country having coastlines on both the Mediterranean and the Black Seas (Pulatsü et al., 2014).

According to the report announced by WWF 2018 (Alessi, 2018), Turkey's most waste originates in the Mediterranean region and 95% of this waste consists of plastic waste. According to the report, 144 tons of plastic per day from Turkey, 126 tons per day from Spain and 90-tons of plastic per day from Italy are thrown into the sea (Alessi, 2018) . The spread of this pollution is also influenced by factors including urbanization, tourism, and industry, depending on Turkey's population density and distribution. Although the Black Sea and Aegean Seas are among the areas with the highest levels of pollution, especially in the Aegean Sea, other polluting factors include household waste, waste water discharges, agriculture, port activities, maritime traffic, and rivers that flow into the marine and coastal water surface (Subaşı, 2010).

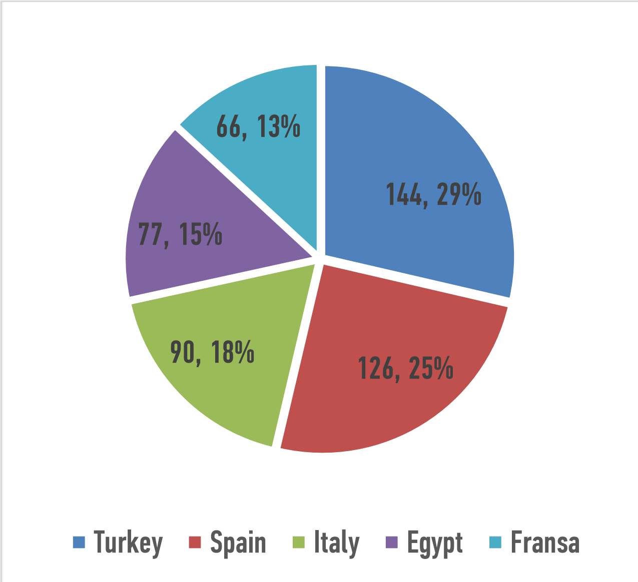


Figure 4. Countries that dump the most plastic waste into the Mediterranean (Source: WWF, 2018)

The waste hierarchy is shifting, thus local governments in tourist regions should build their waste management infrastructures in line with this strategy in order to manage the seasonal surges in waste production. In this context, it is necessary to collect and report consistent data publicly in a traceable system, and effective monitoring and implementation that can be supported by appropriate digital systems. One of the crucial steps the industry must take in this regard is to invest in and develop cutting-edge marine technologies to develop recyclable or sustainable alternatives. In addition to that, it is crucial to plan the trash collection systems and find a solution for the current issue with any attempt to be made within this framework.

2.2.1. *Causes of Marine Environmental Pollution in Turkey*

2.2.1.1. *Black Sea Region*

The Black Sea, covering a surface area of 423,000 km2 and an average depth of 1,300 m, is facing severe environmental issues caused mainly by anthropogenic activities (Levent et al., 2018). Pollution is the primary problem (Figure 5) in the Black Sea, exacerbated by natural variability and climatic changes. The Black Sea basin is home to approximately 162 million people, and it connects the Mediterranean Sea through several straits which receives pollution from various sources, including rivers, which contribute to its oxygen-poor water (Borysova et al., 2005). Its semi-closed nature, coupled with strong density stratification, inhibits vertical mixing and results in low aeration in deep waters, making life unfeasible for many organisms. The Black Sea has a slow rate of water renewal, and its ecosystem has been severely affected by pollution from various sources, including industrial pollution, agricultural runoff, oil pollution, and direct dumping from ships (Levent et al., 2018). The uncontrolled dumping of industrial and domestic waste into various land and water-based disposal sites on its coasts has severely affected the Black Sea's ecosystem and resources.

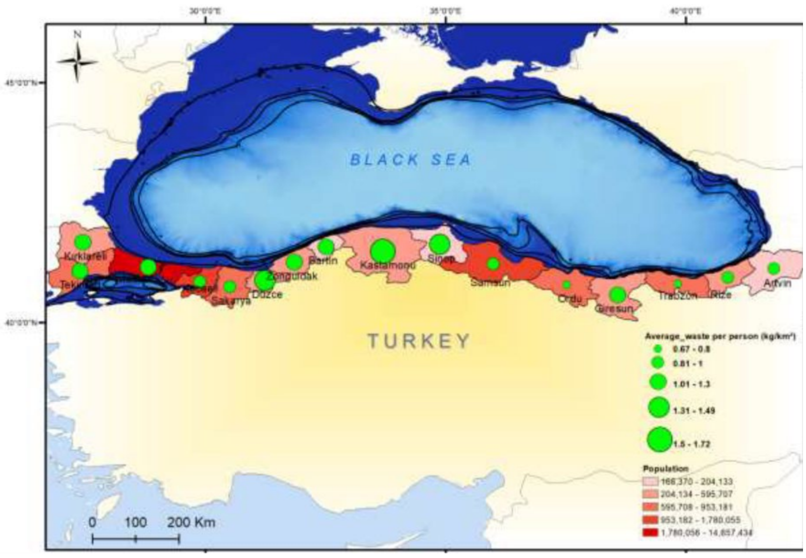


Figure 5. Population and waste generation along the Turkish Black Sea coasts (Source: Levent et al., 2018)

Aquatic pollution affects the aquatic organisms' life cycle, and organic pollution causes an imbalance in the environment, changing the competitive status of the species living in it (Levent et al., 2018), and decreasing species diversity. Benthic organisms (Bat et al., 2016) are the most affected by pollution, and the Black Sea's ecosystem is also threatened by urbanization and industrialization, contributing to the degradation of farmland and the loss of habitat. The sources of pollution in the Black Sea are numerous and varied, including reduced freshwater outflows, pollutants from agriculture and industry, wastewater and other waste from settlements, atmospheric fallout, shipping activities, fishing practices, mineral sources, and recreational activities (Sezgin et al., 2010) . Human activities have altered marine habitats and reduced species diversity. Over-fishing, coastal development, dredging, and the introduction of alien species have also impacted marine life.

The Black Sea region in Turkey faces several environmental challenges such as solid waste issues in residential areas, heavy metal pollution from mining and industry, untreated effluent, erosion, and marine litter. Dumping of waste into the Black Sea is common, as is the deposition of slag and ashes from the Çatalağzı thermal power plant (Turkey, 1995). These pollutants can accumulate in organisms, especially in benthic organisms, which can harm people who consume them. Marine waste originates from various human activities, negatively impacting the environment, wildlife, and economy. All types of waste, including toxic and dangerous materials, are a growing problem in the Black Sea region.

To address hazardous waste, production must be reduced. Bulgaria and Romania are the only European Union member states that fish in the Black Sea, while Turkey is developing regulations to control pollution. However, there is a lack of comparable data on pollution in Black Sea coast countries. Urgent action is needed to protect the Black Sea, and riparian countries should cooperate to implement permanent measures and penalties against polluters.

The Black Sea faces significant environmental challenges that require urgent attention. The sources of pollution are diverse and need to be addressed through collaborative efforts by riparian countries. Sustainable development practices, including reducing waste production and regulating fishing practices, are necessary to preserve the Black Sea's ecosystem and resources. The Black Sea is a vital resource, and it is essential to take immediate action to protect its ecosystem and ensure its sustainability for future generations (Oral, 2013).

2.2.1.2. The Mediterranean region

The Mediterranean Sea is the largest and deepest enclosed sea on Earth and has been subject to marine litter for decades (Zambianchi et al., 2014). This is due to intense shipping, fishing and tourism activities and the presence of 7% of the world's population living around its coastlines (UNEP, 2012). In the Mediterranean Sea, micro-fibers have emerged as a significant environmental concern due to the sea's semi-enclosed nature and high levels of human activity along its coasts (Santini et al., 2022)

Many studies have investigated the abundance and distribution of marine waste in the Mediterranean, including on the sea floor and in shelf habitats, and recently on deep-sea habitats. A recent global numerical model found (Lebreton et al., 2012) that the Mediterranean Sea has one of the highest concentrations of marine waste in the world. Although there is a spatial heterogeneity in waste distribution, no clear pattern of surface debris accumulation has been identified yet, and evidence about the existence of one or more "Mediterranean garbage patches" is still lacking (Zambianchi et al., 2014). There is still little known about litter displacement and accumulation dynamics in the basin.

The Mediterranean Sea receives micro-fibers from various sources, including natural and anthropogenic sources. Natural sources of micro-fibers include erosion of soils, rocks, and vegetation, while anthropogenic sources include textiles, plastics, and personal care products (Santini et al., 2022). The study (Yabanlı et al., 2019) found the most significant factors affecting microplastic pollution in the intersection of the Aegean and Mediterranean region are believed to be yacht tourism activities and population increase during the summer. Geographical factors such as the Aegean Sea's indented coastline and climatic factors such as current direction and force, wind speed, and rainfall amount also contribute to microplastic accumulation (Yabanlı et al., 2019). The effects of these factors on marine ecosystems in Turkey have not been studied consistently.

Textiles are the most significant source of micro-fibers in the Mediterranean Sea, with synthetic fibers such as polyester and nylon being the most commonly detected types

(Pedrotti et al., 2021) . Plastic pollution is also a significant contributor to micro-fibers in the Mediterranean Sea, with microplastics from fishing gear and single-use plastics being the most commonly detected types. Micro-fibers can pose a significant threat to the marine ecosystem. They can be ingested by a wide range of marine organisms, from plankton to fish, and can accumulate in the food chain, potentially affecting human health. Micro-fibers can also damage the digestive system and other organs of marine organisms, leading to reduced reproductive success and growth rates. Furthermore, micro-fibers can alter the chemical and physical properties of seawater, leading to changes in the marine ecosystem's nutrient cycling and overall health. By reducing the sources of micro-fibers and promoting sustainable practices, it is possible to protect the marine ecosystem's health and preserve the Mediterranean Sea's resources for future generations. In addition to that, further studies are needed (Zambianchi et al., 2014) to determine the transport mechanisms of marine litter in the Mediterranean and the dynamics of waste displacement and accumulation in the basin.

2.2.1.3. Aegean region and İzmir Bay

Izmir Bay, located within the Aegean Sea (Figure 6) and surrounded by the Izmir Metropolitan Municipality, holds considerable cultural and economic significance. With a surface area exceeding 500 km2 and a water capacity of 11.5 billion m3, the bay has been divided into three sections, namely Outer, Middle, and Inner, based on the distinct physical properties of different water masses (Kucuksezgin, 2011).

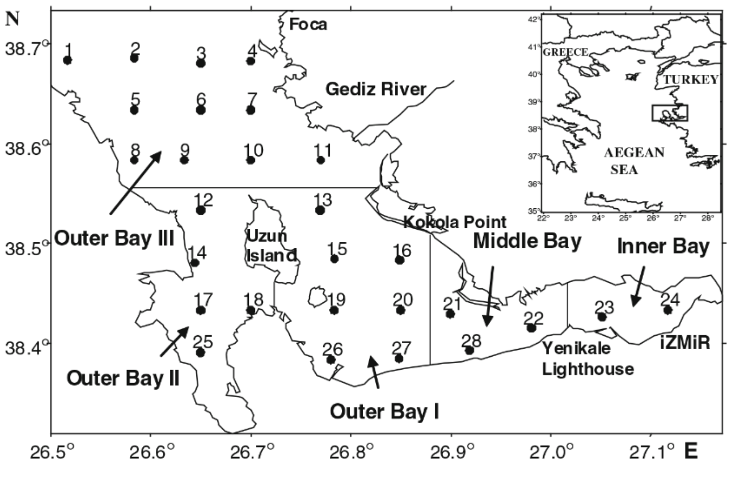


Figure 6. Key geographic features of different sections of Izmir Bay (Source: Kucuksezgin, 2011)

The Outer Bay, extending from Kokola point to the bay's mouth, exhibits relatively low pollution levels, making it a wildlife conservation area. However, the Gediz River, which flows into the Outer Bay, carries a substantial amount of pollution due to the dense population and agricultural and industrial activities in the surrounding areas. The Middle Bay, located between the Yenikale lighthouse and Kokola point, has a water volume of 9×108 m3 and retains pollutant concentrations intermediate between those found in the Outer and Inner Bays (Kucuksezgin, 2011) .Due to its shallow nature, the Middle Bay has limited water exchange and self-purification capacities.

The Inner Bay is heavily polluted with organic material and nutrients, encompassing a water volume of 6×108 m3 and an average water depth of approximately 7 m. The northern part of the Inner Bay has experienced sedimentation from the Gediz River, leading to shoaling issues for the Izmir Harbor (Ozkan et al., 2008). Domestic and industrial effluents are the main sources of pollution in the bay.

In a study conducted by Cebe and Balas (Cebe and Balas, 2018) over a one-year period from March 2015 to April 2016, the water quality of Izmir Inner Bay was assessed, and pollution sources were investigated. The study revealed that nearby wastewater treatment plants (WTPs) and drainage canals were critical sources of pollution for the bay. The overall water quality level of the bay was evaluated as poor, with a hypertrophic trophic state. However, dissolved oxygen concentrations were within normal range at all measurement points, and nitrite and nitrate nitrogen concentrations generally met Turkish regulations. Concentrations of these substances were found to increase in the Çiğli region due to anthropogenic activities such as effluent discharge from WTPs and surface runoff from agricultural practices (Cebe and Balas, 2018) . Effective management strategies are essential to reduce pollution levels and safeguard the ecological health of Izmir Inner Bay.

Nutrient oligotrophic or eutrophic conditions have several impacts on the local marine ecosystem. Oligotrophy is associated with negligible concentrations of nutrients, while eutrophication occurs when nutrient or organic matter enrichment from external sources leads to high biological productivity. Eutrophication is characterized by excessive proliferation of plankton and algae in large aquatic ecosystems, such as lakes, due to a significant increase in nutrients, particularly those originating from land (Borysova et al., 2005)

Eutrophication, a common problem in many coastal areas, arises from poor water exchange and nutrient inputs from rivers and urban activities. Izmir Bay is one such area affected by coastal and industrial development. The water quality of Izmir Bay has been significantly impacted by the Gediz River (Kucuksezgin, 2011), which receives inputs from surrounding agricultural and urban areas. Nutrient and organic matter inputs from domestic sewage, industrial waste, and agricultural practices contribute to eutrophication in the bay (Balkas and Juhasz, 1993) .

2.3. Marine Environmental Management Strategies

The concept of ecosystem management has been put forth as a means to ensure the sustainability of various products and services, with the goal of creating innovative coastal and marine management strategies in numerous countries and regions. To ensure a sustainable future, it is crucial to prioritize the conservation of marine ecosystems.

The ecosystem-based management system suggests (Sardà et al., 2014) a system for managing ecosystems that involves three main components or pillars which adheres to a formal classical environmental management system (EMS) that incorporates a risk-management system (RMS). These pillars are designed to help integrate an ecosystem-based approach into policies for coastal and ocean areas. This approach aims to protect health and productivity as a resource planning and management approach that integrates the connections between soil, air and water and all living things (Farmer et al., 2012).

The first pillar is responsible for considering environmental factors in risk management. The second pillar focuses on governance to ensure compliance with environmental principles. The final two pillars are concerned with obtaining up-to-date scientific advice and facilitating communication and consultation to promote the ecosystem approach.

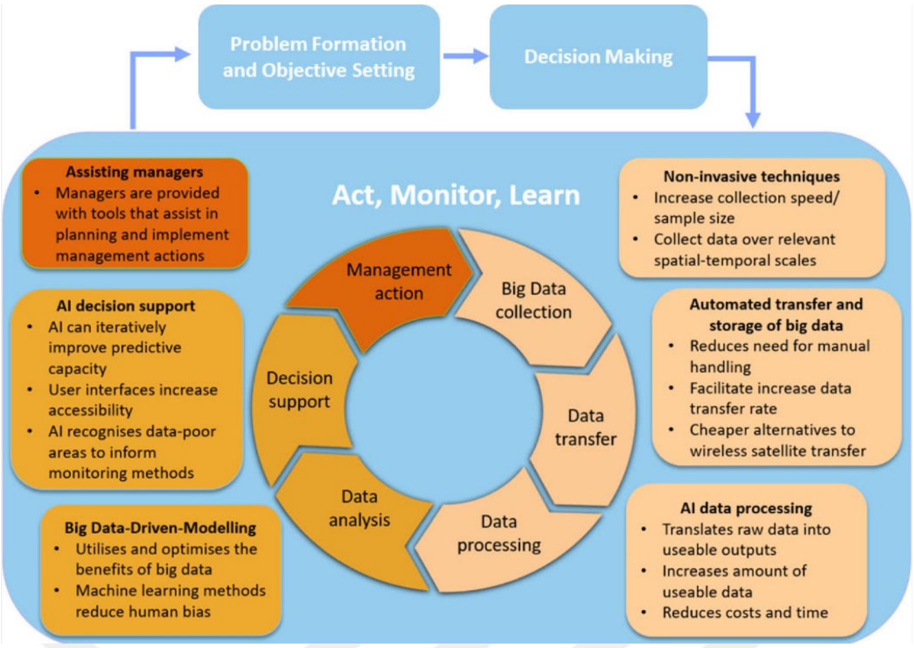


Figure 7. Conceptual, cyclical diagram for the capacity for an automated system of monitoring and management action (Source: Ditria et al., 2022)

2.3.1. Managerial pillar

The managerial pillar is the core of the ecosystem-based management system and is based on a formal environmental management system that operates on the policy cycle assessment. The ecosystem-based management system is a vision-driven process that sets quantitative, clear, and verifiable goals for environmental performance, linked to outcomes. A competent authority is designated to set up and run the system, and stakeholders should fully understand and agree how it is to be implemented in decision making.

Understanding complex ecosystem processes is crucial for decision-making and efficient conservation management.

It follows the classical plan–do–check–act managerial policy scheme and is an iterative, continuous, quality-improvement model consisting of four repetitive steps which are planning phase, Implementation phase, checking and corrective measure phase, reviewing phase (Sardà et al., 2014). The planning phase selects a series of prioritized actions for progress toward the desired vision, while the implementation phase puts the plans into practice.

The checking-and-corrective-action stage involves compliance monitoring programs, including monitoring of program activities, compliance verification, and audits. Inadequate monitoring of ecosystems can lead to poor management decisions that can harm the environment; despite being promoted as environmentally friendly (Ditria et al., 2022).

It is essential to gather adequate data through dependable monitoring techniques, and managers should communicate about their monitoring approaches to ensure their suitability for management requirements. There is a pressing requirement for precise, economical, and easily accessible solutions to guide management at the appropriate level (Dietze et al., 2018). To aid in decision-making and promote adaptive management, automation of data collection, transportation, and analysis through the use of artificial intelligence (AI) can help alleviate some of these obstacles. The current state of AI and automation in marine science can be improved to enable automated monitoring and enhance predictive modeling capabilities for decision-making. Ecosystem monitoring at pertinent spatial and temporal scales can be done automatically using artificial intelligence (AI). This is a cost-effective and efficient method that Machine learning (ML), a subset of artificial intelligence (AI), is used to improve model performance by learning from data. While there are knowledge gaps in automation processes, implementing automation and AI in conservation management can lead to successful outcomes for conservation managers. Therefore, there is significant potential for improving monitoring and management in marine science through the use of AI and automation.

In ecosystem approach frameworks, the involvement of stakeholders is essential, and their inclusion in decision-making processes holds significance. Incorporating a risk-management standard and environmental management system is a widely recognized strategy for attaining environmental objectives (Cormier et al., 2010). The managerial aspect of these frameworks guides users in progressing towards their envisioned goals through iterative adaptive management cycles.

2.3.2. The information pillars

The information pillar of ecosystem-based management provides data to inform decision-making for risk assessment and management. Spatial data is essential to implement the ecosystem approach, but ownership and scale issues can create challenges. The European Marine Observation and Data Network is an emerging spatial data infrastructure that can support this approach. Spatial modeling and mapping can be used to make informed decisions, and an example of a spatial data infrastructure structure for marine management.

New technologies can help collect data remotely, but they are often expensive, which limits the sample size collected and creates uncertainty in the data. Manual data collection is important for community engagement and education, but AI can be integrated with citizen science to ensure the benefits of both.

The advancement in computational power and the prevalence of big data in all fields may allow machine learning to adapt quickly and continuously to changing environments, (Figure 7) providing accurate near real-time prediction of complex environmental processes.

Automation is the use of technology to replace or eliminate human participation. After deployment, automated systems may require little input and reduce operating expenses. According to studies, revolutionary monitoring techniques utilizing automation and AI have significantly reduced operating costs which demonstrated a 99% cost reduction over conventional techniques at 200 times the speed (Ditria et al., 2022). Deep learning algorithms can quickly and accurately process large amounts of image-based data, which can help managers make informed decisions about conservation management. This technology can analyze data without the need for manual feature extraction, making it more efficient and reliable than traditional methods.

Studies have shown that Machine Learning can help handle the labor-intensive challenges of acquiring empirical data on microplastics, providing more data to improve models and aid in monitoring and optimizing data sampling and collection (Marin et al., 2021).

2.3.3. Participatory pillars

The ecosystem approach requires multisectoral participation from all levels of society, sectors, and stakeholders in order to be effective. However, levels of public understanding about the marine environment are low and not all actors have the same capacity to participate. The participatory pillar of the ecosystem-based management system aims to build capacity and communication with stakeholders.

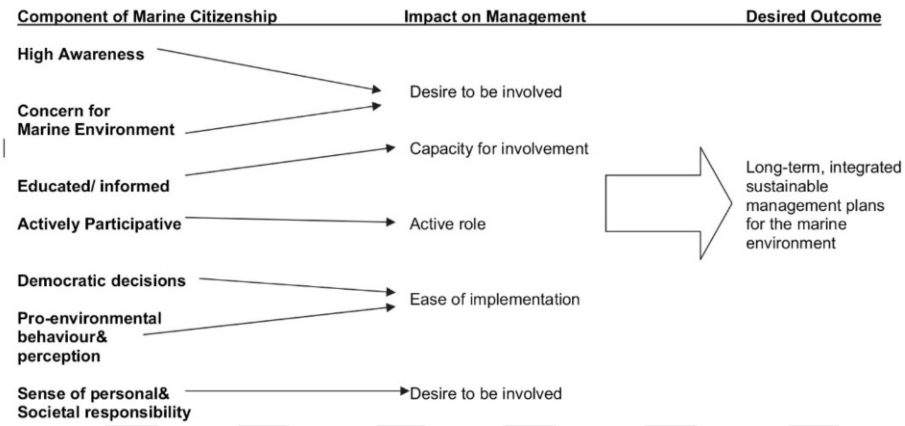


Figure 8. Influential factors of marine citizenship and their impact on successful management of the marine environment (Source: Seyfang, 2005)

Marine citizenship is import aspect for the marine environment which builds upon the traditional notion of citizenship, which emphasizes collective contributions (Figure 8) to social, economic, and environmental goals (Seyfang, 2005). It expands the concept to include environmental behavior and attitudes to encourage individuals to reduce their negative impacts on the marine environment. By recognizing the public as key actors in marine policy development and implementation, marine citizenship offers a more sustainable approach compared to solely government-driven policies (McKinley and Fletcher, 2010).

According the research, there is strong support for marine citizenship as a means of facilitating policy implementation by linking individual behavior to the quality of the marine environment (Ducrotoy et al., 2000). Targeted marine education is seen as crucial for enhancing societal understanding and generating a willingness to change behavior which raises broader questions about the feasibility of achieving high levels of marine citizenship that result in tangible improvements to the marine environment (McKinley and Fletcher, 2010). Given the complex governance and varying societal attitudes across nations bordering oceans, this poses significant challenges. However, marine citizenship offers a potential avenue for building a new relationship between the state and citizens focused on marine environmental renewal.

2.3.4. Regulations and policies

The concept of modern ecosystem restoration was first introduced by Aldo Leopold in the 1930s, but humans have been taking restoration-like actions in coastal and marine ecosystems for millennia. Ecosystem restoration has since evolved and expanded from terrestrial into freshwater and marine systems and is recognized as crucial to support the recovery of marine life due to declines in marine species, habitats, and ecosystems.

The Marine Strategy Framework Directive (MSFD) mandates EU Member States to ensure the absence of significant risks to marine biodiversity, ecosystems, human health, and legitimate uses of the sea. Rather than focusing solely on the structural aspects, the MSFD emphasizes the monitoring and assessment of marine ecosystem functioning, with the objective of attaining Good Environmental Status (GES) by 2020 (O'Higgins and Roth, 2011). Each Member State is obliged to formulate an iterative strategy for its marine waters, encompassing assessments, determination of GES, establishment of targets, indicators, and monitoring, along with a set of measures to achieve or uphold GES. In their initial assessments under the MSFD, three Member States predominantly employed the DPSIR framework, particularly in the context of their socio-economic analyses.

Finding the factors that influence effective restoration and monitoring advancement toward international restoration and conservation goals are difficult tasks for scientists, practitioners, and policy makers. Although there is a lot of research on marine and coastal restoration, it has not been effectively converted into information that practitioners and policy makers could use. Moreover, existing restoration project monitoring and reporting practices frequently solely evaluate ecological features, leaving out ecosystem services and their associated socioeconomic benefits. To evaluate effectiveness and enhance restoration tactics, a better monitoring and reporting system for restoration outcomes is required (Suding, 2011).

The creation of a restoration reporting framework (RRF)is to standardize the reporting of marine restoration projects and make it easier to compare and learn from them. The framework would include a set of standardized metrics, a protocol for storing and accessing the information, and be applicable to all coastal, habitat forming ecosystems. This framework is needed before the number and magnitude of restoration projects accelerates further, and that it will improve evidence-based decision making for future marine restoration.

CHAPTER 3: MARINE ENVIRONMENTAL MANAGEMENT TECHNOLOGIES

In the last five decades, environmental monitoring has significantly benefited from remote sensing technology (Xiao et al., 2019). Advanced sensing and information and communication systems technologies that make up the technological network offer more efficient and various parameters with the existing infrastructure evaluation and modeling systems. This data is collected through the IoTs of millions of devices working in the marine and coastal environment and processes the existing information by creating Big Data. With the development of a global sensorization system in digital infrastructure components, it system monitors manage environmental conditions by accessing data from different networks with many devices (Xu et al., 2019). The real-time collection of data and its integration with autonomous marine technologies will greatly contribute to the smart infrastructure of the marine environment and operational efficiency.

3.1.Marine debris and waste management technologies

The researchers (Ribeiro et al., 2021) emphasized the threat posed by climate change brings many challenges about the environmental problems. Therefore, we need to consider the efficiency in transportation networks, use of renewable energy and an integrated coastal and Marine Environmental Management technologies.

Monitoring the sources of marine litter requires regular surveys and analysis, considering local weather conditions and coastal geomorphology which harmonizing monitoring methods and reporting categories across different environmental compartments is crucial for accurate source attribution (Galgani et al., 2011). Long-term monitoring is necessary to understand trends, and it should consider spatial and temporal scales (Hanke et al., 2013). Priority should be given to monitoring the most affected marine areas. Protocols and standards exist for assessing litter on coastlines, and these should be adjusted and harmonized for the implementation of the MSFD and extension to other regions. Aerial observation, image recognition systems, trawling surveys, and indicator species can be used for monitoring different types of litter.

The Venn Diagram designed by Helinski (Helinski et al., 2021) provides a framework

(Figure 9) for understanding plastic waste capture devices in freshwater and coastal water bodies. Synergic devices are defined as devices containing two components (blue diamond). All-inclusive devices contain three components (yellow symbol).

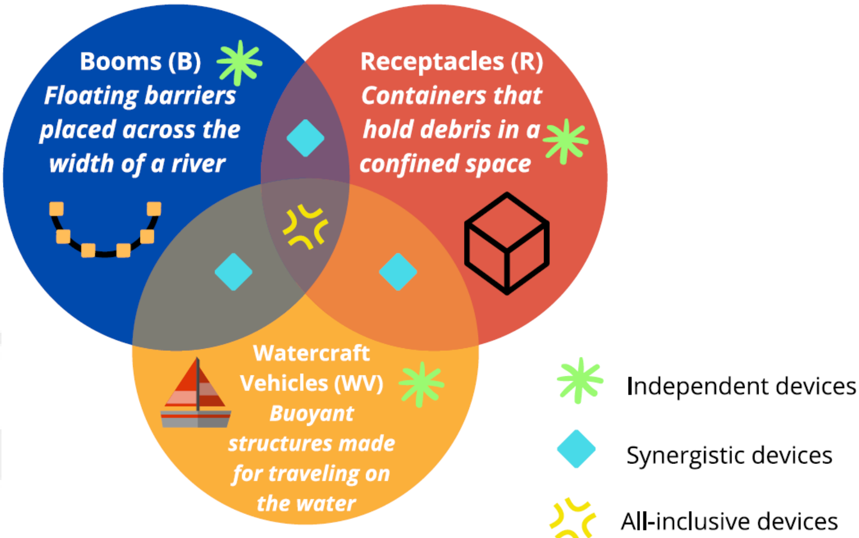


Figure 9. Helinki's Venn Diagram (Source: Helinski, Poor and Wolfand, 2021)

Helinski has divided these types of devices into Boom, receptacle and Watercraft Vehicle to separate component types (Helinski et al., 2021) . Boom is defined as a barrier device used to divert waste or prevent its continued flow, Receptacles are defined as a container type device that can accumulate and hold waste in a confined space, and Watercraft Vehicle as a floating structure device made for traveling on or in water Devices using one component are defined as stand-alone devices, Synergistic devices using two components, and devices using all components are defined as all-inclusive devices. All-inclusive devices using booms, Receptacles, and watercraft have a more complex design system than stand-alone or synergistic devices.

3.1.1. The Impacts of Marine Waste Management technologies on the Environment and Marine Life

Coastal zones, characterized by high population density, necessitate economic development to support human welfare. However, this pursuit of economic growth can have detrimental effects on the environment, which in turn affects human well-being. Coastal and marine management face challenges arising from insufficient data and limited data access in many countries. Effectively managing these intricate social-ecological systems requires the implementation of tools and frameworks capable of addressing and integrating multifaceted issues (Maximenko et al., 2019). Although various frameworks have been developed, the acquisition of essential environmental data for their application poses difficulties, particularly in countries where reliable data accessibility is limited (Xiao et al., 2019). Remote sensing technologies, (Figure 10) encompassing satellite remote sensing, aerial remote sensing, unmanned aerial vehicles, unmanned surface vehicles, unmanned underwater vehicles, and static sensors as ground methods, are increasingly being employed to monitor coastal and marine environments. These technologies hold the potential to enhance integrated coastal and marine environmental management, primarily based on the Driver–Pressure–State–Impact–Response framework and its updated version, DAPSI(W)R(M) (Elliott et al., 2017). Concrete examples are presented to illustrate how these technologies can prove beneficial for all components of the framework.

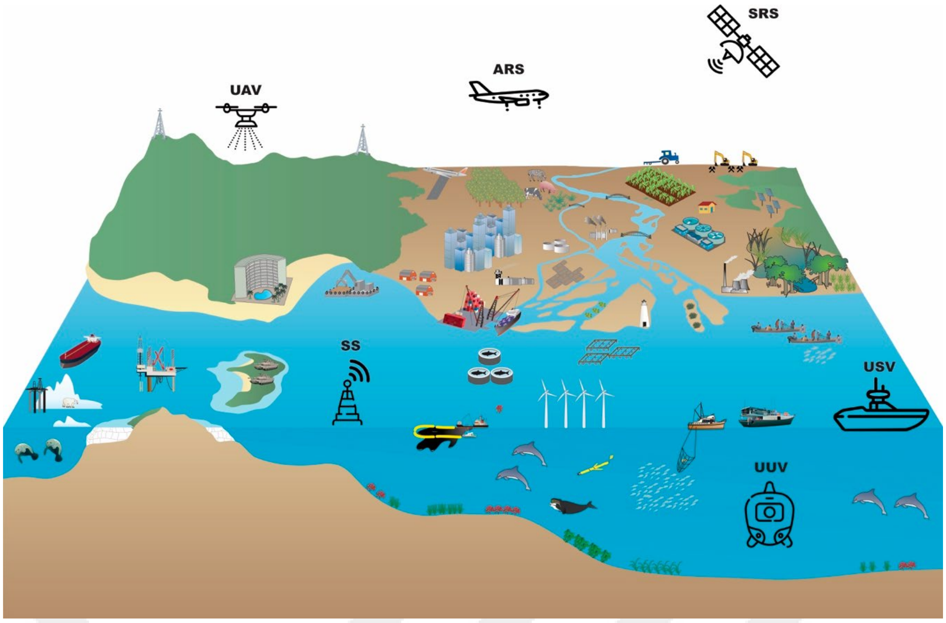


Figure 10. Conceptual diagram summarizing the main activities in coastal and marine environment management technologies (Source: Mahrad et al., 2020a)

Satellite Remote Sensing (SRS) began in the 1970s with Landsat 1 and was followed by the Coastal Zone Colour Scanner, the first satellite designed to monitor the Earth's oceans and water bodies (Krug et al., 2017). Many other satellite sensors have since been developed by various space agencies and countries. SRS images and techniques are advantageous because they usually collect uniform data with common acquisition and recording schemes, covering large areas.

Aerial Remote Sensing or Manned Aircraft (ARS) involves taking photographs from a human-crewed aircraft, and has been used for coastal research, such as wetland assessments, beach erosion control, and land-use planning.

Unmanned aerial vehicles (UAVs) or drones are unmanned aircraft that can reach difficult locations and have been used for coastal and marine survey, among other things.

Unmanned Surface Vehicles (USVs) and Unmanned Underwater Vehicles (UUVs) are robotic devices or vehicles that operate on the water surface or underwater, respectively. Static Sensors (SS) include single sensors or wireless sensor networks (WSN) and are useful for coastal and marine environments, but only provide local observations as they are typically fixed sensors (Mahrad et al., 2020a).

While remote sensing can detect and classify marine debris, developing autonomous and field deployable sensors for marine debris, including microplastics, remains a significant research challenge (Maximenko et al., 2019). Samplers, such as beach litter surveys and plankton nets, are used to collect debris samples for subsequent analysis.

3.1.2. Challenges and Opportunities for Improving Marine Debris Management

About the challenges faced by various remote sensing technologies when applied to coastal and marine ecosystems is, for SRS, the resolution of satellite data is generally coarser, limiting its ability to assess specific targets, pressures, and state changes. ARS missions remain expensive, and collected data may be ambiguous for specific targets. UAV missions are often costly and limited by flight duration, altitude, weight capacity, and operational safety. USV guidance and navigation, as well as sensing, face limitations, and surveys under extreme weather conditions remain challenging (Mahrad et al., 2020a) UUV encounters challenges related to positioning, light refraction, underwater clarity and turbidity, potential risks for disturbing animals, and collision avoidance between multiple UUVs. SS has limitations in coverage, expansion, and communication between devices. Various remote sensing technologies face challenges when applied to coastal and marine ecosystems, including limitations in resolution, cost, flight duration, altitude, weight capacity, operational safety, guidance and navigation, sensing, positioning, light refraction, underwater clarity and turbidity, potential risks for disturbing animals, collision avoidance, coverage, expansion, and communication. A global observing system is necessary (Maximenko et al., 2019) to monitor the impacts of marine debris and develop strategies to mitigate them.

While such solutions are feasible, they cannot be scaled to remote uninhabited islands where plastic litter is found in large volumes. To create a meaningful impact, significant seed funding needs to be provided.

3.2. Monitoring and Surveillance Technologies

The proliferation of marine plastic litter has emerged as a pressing global concern, impacting densely populated regions as well as remote areas like the Arctic. Anthropogenic activities, both on land and at sea, constitute the primary sources of marine litter, and the slow degradation rates of plastic waste worsen the situation Consequently, investigating marine plastic litter assumes a critical role in managing and monitoring its detrimental effects on oceans and shores. Various organizations have been established to address the ecological challenges posed by marine plastic litter. However, the insufficient global-scale monitoring and surveillance hinder effective resolution due to inadequate information and coordination among different regional organizations (Winijkul et al., 2023). To tackle this issue, monitoring programs and guidelines have been developed by different entities, such as the Global Initiative on Marine Litter, Group of Experts on the Scientific Aspects of Marine Environmental Protection, and Marine Strategy Framework Directive. Long-term assessment and survey programs must be implemented to assess the pollution level or state, enabling the formulation of effective plastic survey plans and promoting adaptive management. Reliable data regarding the occurrence of marine plastic litter and mitigation plans are essential for adhering to accepted standards and practices. The success of monitoring programs relies on a robust monitoring strategy encompassing four key aspects: surveillance monitoring, implementation monitoring, effective monitoring, and ecological effect monitoring (Hanke et al., 2013). The presented guidelines incorporate modern technologies and sampling equipment, emphasizing the standardization of data and reporting to ensure statistically reliable analysis of all debris types. Instructions are provided within the guidelines for estimating debris concentration in various scenarios, including shorelines, surface waters, visual surveys at sea, and benthic surveys (Lippiatt et al., 2013).

The choice of measurement units for assessing marine litter depends on factors such as the sampling location, debris size, and monitoring program policies. When evaluating litter abundance on shorelines, the number of litters is more suitable, whereas the mass of litter becomes more significant when considering litter management. Assessing microplastics poses challenges due to their small size (Eriksen et al., 2014) and low concentration in the natural environment, with the number concentration commonly used to report their abundance. Metadata plays a crucial role in ensuring the reliability of monitoring data, and clear data management policies are essential for quality assurance, quality control, storage, sharing, reporting, and publication (Lippiatt et al., 2013). Therefore, quality assurance procedures guarantee that the samples follow the standard procedures or standards qualified by experts. Thus, quality assurance procedures ensure that samples adhere to standard procedures or standards endorsed by experts, while quality control examines the quality and quantity of field survey data. Litter categories are significant in mitigation planning (Winijkul et al., 2023) and can provide insights into the potential sources of litter. The categorization of litter tends to be hierarchical and depends on the policies or objectives of the organization that develops the standard guidelines.

Rapid assessment surveys are commonly conducted before establishing a monitoring program to assess the impact of natural disasters, relying on visual inspections to generate qualitative and semi-quantitative estimates of litter abundance and waste composition (Winijkul et al., 2023). Rapid assessments can also incorporate citizen science to gather information and address related issues. Additionally, satellite image data and innovative techniques like aerial imagery from drones can be employed for rapid assessments (Doyle et al., 2011).

The environmental monitoring and waste management process has been experiments using high-resolution SRS (Satellite Remote Sensing) imagery for automatic digital classification of marine waste by collecting data with deep learning based software (Moy et al., 2018). Using machine learning algorithms and vast datasets to analyze complex maritime environments, autonomous vessels could increase confidence in remote and autonomous operations' capabilities and safety benefits. In the maritime industry, by developing artificial intelligence and machine learning algorithms in remote and autonomous ship systems, a system that works safely on its own without human intervention, improves the performance and environmental gains of ships, and analyzes, and collects larger data sets will be essential in the future (The Department for Transport, 2019).

Figure 11. USV operation (Source: Shojaei, Moud and Flood, 2018)

The study (Shojaei et al., 2018) explores the possibility of using small, low-cost USVs for built environment management, and presents a proof of concept for such a device. A feasibility study was conducted at a retention pond in Gainesville, Florida to test a small, low-cost USV in a practical situation for structural health monitoring and maintenance. The USV (Figure 11) used in this study is remotely controlled and mounted with a waterproof camera. Two rounds of data collection were conducted to ensure the quantity and quality of data. The goal of this experiment was to provide proof of concept for the use of such devices in monitoring the construction work to facility management and possible disaster relief efforts. The captured data can be used for visual inspection, automatic environment detection, and crack detection.

It proposes an approach that uses open-source software and machine learning algorithms to provide real-time data analysis on the device, rather than later on with proprietary software. The approach offers a low-cost, customizable, and versatile solution for automating the monitoring and maintenance of the built environment, compared to expensive proprietary software and conventional image processing algorithms. A random forest algorithm is trained to segment air, concrete, and water in the pictures, (Figure 12) and the results are presented. The approach enables training to be conducted once off-site, reducing the need for expensive computations during real-time use.

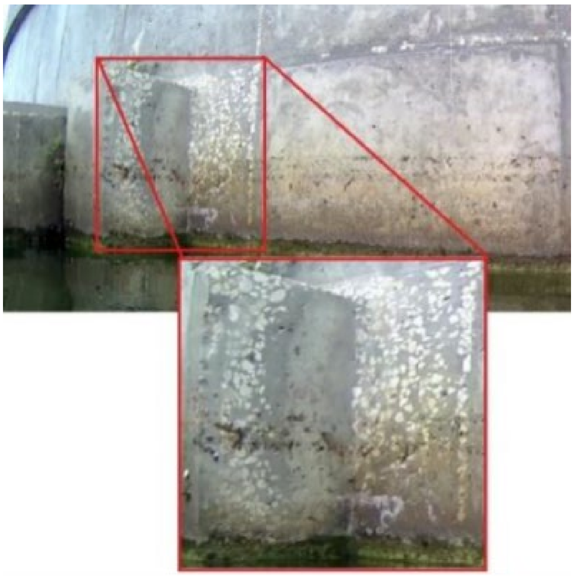


Figure 12. Visual inspection result (Source: Shojaei, Moud and Flood, 2018)

3.3. *Autonomous Maritime Technologies*

The future of autonomy (Ribeiro et al., 2021) is geared towards improving the quality of city life and the development of more citizen-focused systems that provide accessibility and inclusion (especially an increase in the activities of the old and young) while reducing environmental impact and pollution. Technological advancements such as the use of data and analytics, artificial intelligence (AI) and machine learning, the advancement of sensor technology, and advancements in robotics are key enablers for maritime autonomy and have the potential to have a significant impact on the industry (The Department for Transport, 2019). Future developments in ship design and operation can redefine the shipping industry as we currently know it, even though these technologies can revolutionize how the world functions in terms of business practices, logistics, urban ecology, and social life.

3.3.1. Autonomous underwater vehicles (AUVs)

AUVs are robotic vehicles that capable of maneuvering in three dimensions underwater(Von Alt, 2003) to operate autonomously underwater, without the need for human input. These vehicles are capable of navigating through water using various sensors and on-board computers. They can perform a wide range of underwater tasks, such as mapping the ocean floor, monitoring environmental conditions, conducting underwater surveys, and collecting samples(Danovaro et al., 2016).

A typical AUV is composed of several components, including a propulsion system, a power source, sensors for navigation and data collection, and a communication system for transmitting data to the surface (Stutters et al., 2008). The propulsion system can be electric, hydraulic, or a combination of both, and it enables the AUV to move through the water at a desired speed and direction. The power source can be a battery or a fuel cell, which provides energy to the vehicle's components.

AUVs are equipped with various sensors, such as acoustic, optical, and chemical sensors, which enable them to collect data on their surroundings(Stutters et al., 2008). These sensors can detect and measure various parameters, such as temperature, salinity, pressure, and the presence of specific chemicals or biological species. The navigation system of an AUV typically includes a combination of sensors, such as an inertial navigation system, a Doppler velocity log, and a compass, which enable the vehicle to determine its position and orientation relative to its surroundings.

AUVs are used in a wide range of applications, including scientific research, environmental monitoring, defense, and offshore industries. For example, they can be used to study ocean currents, map underwater features, and monitor the distribution of marine life. They can also be used for underwater inspections of pipelines, oil rigs, and other offshore structures.

3.3.2. Unmanned surface vehicles (USVs)

Unmanned vehicles have emerged as a valuable tool for marine monitoring. They offer advantages such as improved safety, repeatability, reduced costs, and the ability to operate at long distances beyond human observers' detection ranges (Heo, J., Kim and and Kwon, 2017).

They offer advantages such as improved safety, repeatability, reduced costs, and the ability to operate at long distances beyond human observers' detection ranges which can be deployed in the air UAS, at the sea surface, or in the water column (Jorge et al., 2018). Over the past decade, unmanned vehicles have evolved and been used in various studies, including oceanographic and meteorological data collection, sea ice monitoring, and wildlife monitoring. They have also found applications in the Oil and Gas industry for subsea equipment inspections, leak detection, and marine mammal monitoring.

USVs are autonomous or remotely operated vehicles that navigate and perform tasks on the surface of water without the need for human intervention in real-time which possess a variety of sensors, navigation systems, and on-board computers, enabling them to operate and navigate effectively in diverse water conditions (Jorge et al., 2018). USVs are capable of operating autonomously using pre-programmed instructions or under remote control that can carry various payloads, such as sonars, cameras, and sensors, which enable them to collect and transmit data in real-time or for later analysis. Furthermore, they can operate in collaboration with other autonomous vehicles like unmanned aerial vehicles (UAVs) and autonomous underwater vehicles (AUVs), to perform complex tasks and provide comprehensive environmental monitoring. Unmanned vehicles can be deployed in the air UAS, at the sea surface ASV, or in the water column AUV. USVs find extensive use in marine research and industries, and their use is on the rise due to their cost-effectiveness and efficiency in performing various water-based tasks.

CHAPTER 4: AUTONOMOUS SURFACE VESSEL TECHOLOGIES

The future of autonomy (Ribeiro et al., 2021) is geared towards improving the quality of city life and the development of more citizen-focused systems that provide accessibility and inclusion (especially an increase in the activities of the old and young) while reducing environmental impact and pollution. Technological advancements such as the use of data and analytics, artificial intelligence (AI) and machine learning, the advancement of sensor technology, and advancements in robotics are key enablers for maritime autonomy and have the potential to have a significant impact on the industry (The Department for Transport, 2019). Future developments in ship design and operation can redefine the shipping industry as we currently know it, even though these technologies can revolutionize how the world functions in terms of business practices, logistics, urban ecology, and social life

New technologies emerging in the world will be connected to design systems that will facilitate the design in a very short term. The changes in industry technologies affect the future scenarios and innovative solutions that will introduce flexible designing for the future of vessel. As the marine industry moves towards the industry 4.0 era, vessels are becoming smarter with more automated systems and shifting towards unmanned and autonomous vessels (Ang et al., 2019). The industry introducing autonomous ship systems which are the operating system of the ship that can make the decisions and determine the actions by itself. Furthermore, the autonomous system has the ability to handle unforeseen situations by performing problem-solving operations without human intervention.

Examining the future autonomous water surface vessel is crucial to understanding the change of spatial organization in the marine environment. Autonomous vessels can open additional possibilities for upgrading marine and coastal environment consider ensuring cost-

effectiveness in the manage, design, delivery, operation, and maintenance of large infrastructures and networks, by adopting risk-based approaches and network resilience perspectives. While advances in marine technologies have brought with them an unprecedented amount of advances, the use of machine learning techniques to analyze and the infiltration of information technologies into the physical space has opened up tremendous avenues for how we can design and live in the cities (Duarte and Firmino, 2009). Autonomous Surface Vessel technologies may set up new forms of production and design systems which may become part of the built environment and bring a new spatial entity into marine and coastal environment (Nagenborg, 2020).

4.1. The Definition of Autonomous Water Surface Vessel (ASV)

The definition of a surface vessel is a " nonlinear underactuated kinodynamic system often with large inertia " (Chiang and Tapia, 2018) that is constantly in contact with the water's surface. Operation of autonomous vessels can be several modes (Thieme et al., 2019) which are semiautomatic operation with crew on board, semi-automatic operation from a remote-control center located onshore, semi-autonomous operation, and fully autonomous operation.

An autonomous surface vehicle, or ASV, on the other hand, is a ship that is capable of decision-making and mobility without the need for human guidance, navigation, or control. It minimizes human errors and accidents arising from risks in the marine environment and reduces costs issues. The future of transport systems will be more dynamic and efficient which integrating the products and technology modules already existing within the context will be the important concept of the autonomous vessels. As ships become more environmentally friendly and smarter, the digitalization of vessel are getting more attention in the maritime industry (Ang, J. H., Goh, C., Choo, C. T., Juveno, , Lee, Z. M., Jirafe, V. P. and Li, 2019). From scientific study to military operations, it has increased operational capabilities, functionality, and precision in numerous fields. It safeguards employee health and safety by allowing the flexibility to use unpleasant, difficult, and dangerous work.

The Marine Autonomous Surface Ship (MASS) has now been officially recognized by the International Maritime Organization (IMO) (IMO, 2021), the world regulatory agency for safety and environmental protection at sea. The relationship between humans and technology is central to the fields of interaction design and human-computer interaction. Machine learning and AI systems in autonomous systems not only reinforce this interaction environment but also accelerate the decision-making process (Kleinberg et al., 2018) and offers a social benefit by supporting and enhancing human interaction. Developing these technologies in autonomous ships, instead of replacing human decision making when braking and maneuvering, is a positive situation in terms of safety (Veitch and Alsos, 2021). The autonomous surface vessel, especially with advancements in technologies could provide new possibilities for both urban and coastal mobility. In addition, the industry could become cleaner, safer, and more productive due to modern technology such as maritime autonomous systems, which have the potential to revolutionize the industry and pose a threat to established business models (The Department for Transport, 2019).

According to a market intelligence report by BIS Research titled (BIS Research, 2018) Global Autonomous Vessel and Ocean Surface Robot Market: Analysis and Forecast, 2018-2028, "the autonomous vessel market in terms of volume is expected to grow at the rate of 26.7 percent during the period 2024-2035 and ultimately generate a revenue of $3.48 billion by 2035." Designing autonomous systems needs interdisciplinary and interindustry approaches which must accommodate various kinds of software, hardware, design knowledge, and different groups of people.

Ship design plays a key role in the design of Autonomous Water Surface Cleaning Vessel. Vessels might function completely autonomously, with choices made entirely by the machine. Safety, reliability, and security are also key elements (Thieme et al., 2019) for assessing this system which is different than the traditional methods. Cybersecurity is crucial for autonomous vessel, but it is vulnerable to intrusion by hackers. However, the harsh weather, a changing ocean environment, and obstacles create a challenge to the ship operating in open waters (Vagale et al., 2021) . Ensuring the safety of navigation is important for that issue. Additionally, maintenance planning needs to be managed by the system even though autonomous ships operating for extended periods at sea and in marine environments must have status monitoring systems. While cruising, it is necessary to be aware of the variability of coverage and bandwidth with varying degrees of coverage depending on current location (Vagale et al., 2021).

4.2. Navigation and Sensing Technologies for Efficient Cleaning

Technological development will play a crucial role to achieve zero accident and full decarbonization in maritime industry. The significant proliferation of affordably-priced robots in the market has resulted in a substantial surge in the deployment of these systems (Torok et al., 2014). As Information and Information Communication Technology (ICT) and sensor technology continue to advance at a rapid pace, practical applications are being initiated to enhance the navigational safety of autonomous vessels and to improve the working environment in the maritime industry. Traditionally, human operators manage vessels and provide action-related commands using various control tools. However, with the use of sensors, ships can now collect information and perform the operations necessary to complete tasks based on the data obtained. The design of vessel systems that can be monitored and modified by human operators, both onboard and remotely, is implemented in order to enable autonomous navigation. This process involves the integration and synchronization of various components within the vessel, including the hull structure, engine system, communication system, sensors, and navigation, guidance, and control systems (Schiaretti et al., 2017). These subsystems of the autonomous ship form the basis of the autonomous navigation architecture. This (Figure 13) is an example of the flow connection and relationship diagram of sub-electronic and machine systems

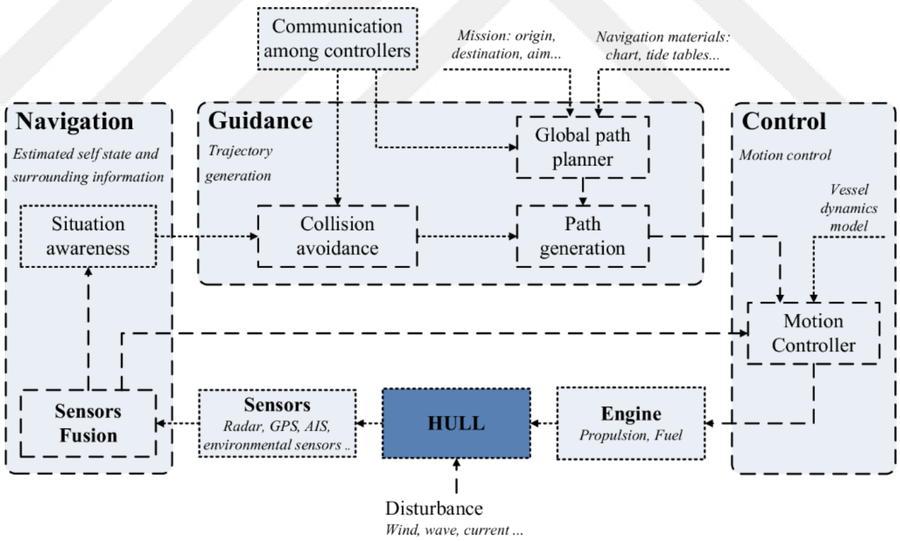


Figure 13. Subsystems in an ASV (Source: Chen, Negenborn and Lodewijks, 2016)

Sensors are referred to as any device that measures the physical environment (such as weather conditions) (Arampatzis et al., 2005) in which equipment is functioning or that measures the state of equipment. While sensors are essential to the operation of high-tech environments like that also integrate and connect a variety of hardware with internet connections and use data to improve services like waste collection and emergency response times in a network known as the "Internet of Things" (IoT). While the sensor technology provides the data collection, it allows the integration of equipment such as image acquisition, control, position monitoring in smart ship systems, while developing it with the machine algorithm, allowing it to interact with other ships and watercraft vessels.

4.3. Communication and Control Systems for ASVs

The rising interest in autonomous unmanned ships in scientific, military, and open and shallow waters has led to an increasing demand for advanced guidance, navigation, and control (GNC) systems. The navigation control system, which consists of a software's, assigns specific tasks to the vessel, takes sensor data, and calculates the desired output using specific algorithms before transmitting it to a module. In addition to that, the communication system provides current status data for the ship and remote-control applications.

With the advancement of maritime technology, Electronic Chart Display & Information System (ECDIS), global positioning system (GPS), automatic plotting radars (ARPA), Automatic ship identification system (AIS), (Figure 14) testers etc. uses in different ways. The rules written for ships under human control are updated to include autonomous ships. The working principle of AIS (Svanberg et al., 2019), position data from GPS, bow and speed dynamic information from gyro and compass, and speed dynamics information from longline, physical parameters of the navigating ship (such as limited maneuverability) It works over a system that broadcasts static information such as ship name, IMO and MMSI numbers. The Automatic Identification System (AIS) is a system that helps to exchange information with other ships and the coast station via antenna for navigational safety. The autopilot system is a system that works with gyro and magnetic compass and performs the setter duty on the desired route by adjusting the rudder angle.

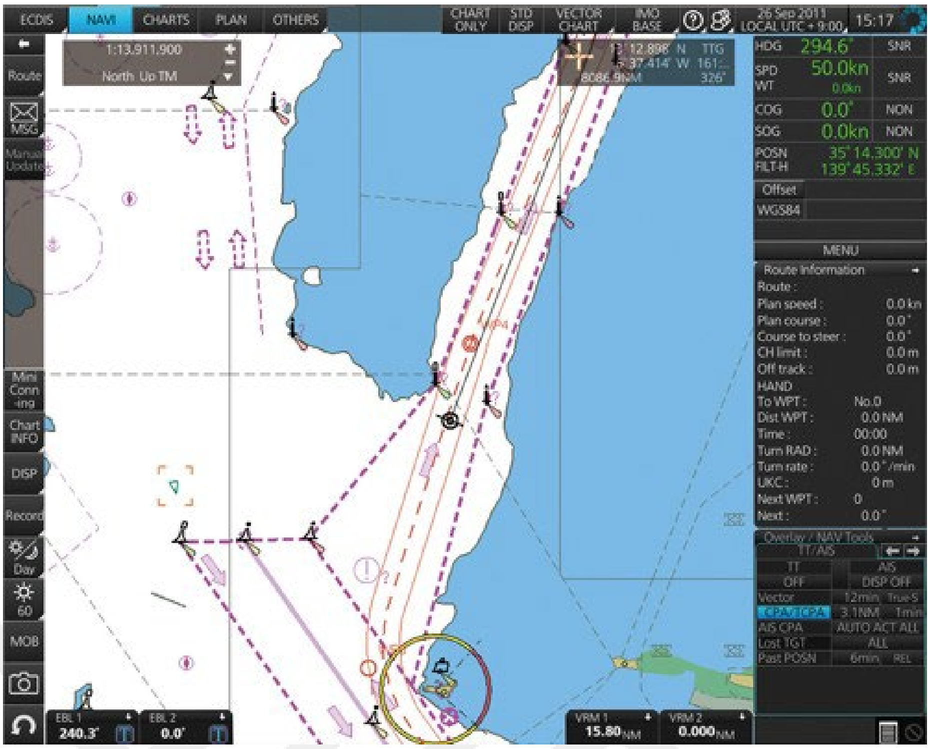


Figure 14. Automatic Ship Identification System (AIS)

The autonomous navigation system (ANS) consists of different modules such as route planning (RP) module, situational awareness (SA) module, collision avoidance (CA) module and a ship state detection (SSD) module (Stenman and Öhland, 2017). Motion planning is difficult because surface ships are often kinodynamic systems with large inertia and non-linear orientation. Decision modules of ships with autonomous systems consist of interconnected distributed intelligence and sub-modules. Although each mode has its own mission dynamic, each of them creates a single system in connection with each other. In addition, the vessel status indicator is not recommended for safe navigation and a different system should be designed compared to a traditional ship system. Many sub-systems such as route tracking and turns, ship traffic density tracking and collision avoidance, current and tide tracking, depth tracking, maintaining the distance to the shore, and weather tracking need to work in an integrated manner by displaying a versatile behavior.

4.4. Energy Management and Environmental Considerations

The fuel efficiency of a vessel and emissions output can be improved through various strategies, including optimizing the hull design and implementing cooperative measures like ship speed reduction, voyage planning, and weather routing (Morrow, 2018). The IMO (Bullock et al., 2020) aims to reduce GHG emissions from shipping and has set a target of reducing emissions by at least 50% by 2050 compared to 2008. The Energy Efficiency Design Index (EEDI) is a regulation that requires new ships to be at least 30% more energy efficient than older ships and is designed to increase the energy efficiency of new ships over time. Using batteries as a power source, electric propulsion can be employed across all types of ships, as demonstrated by its successful implementation in ferries and offshore support vessels, leading to improved efficiency and lower fuel usage.

4.5. Applications of Autonomous Water Surface Vessel for Environment Management

Autonomous Surface Vessels (USV) have been used for many aspects of marine management, including bathymetry surveys (Roberts and Sutton, 2006), sea surface sampling, environmental data collection, pollutant tracking (Naeem et al., 2008), and managing and collecting waste from the marine surface (Phirke et al., 2021), in addition to measuring activities both above and below on water. These vessels applications of Autonomous water surface Vessel, although still in its early stages, have the potential to manage and monitor many types of waste that may be found on shores and at sea, including microplastics as well as many other wastes (Mahrad et al., 2020b). In addition, these technologies have been used to monitor water quality status and ecosystem status, in relation to environmental management

4.5.1. Mayflower Autonomous Ship

The Mayflower Autonomous Ship (Figure 15) is intended to investigate how global oceanic climate change is influencing marine life, gather knowledge that can revolutionize the shipping and marine research industries, and determine how human activity affects marine ecosystems. The vessel has been designed and planned in accordance with the International Regulations for the Prevention of Collisions at Sea (COLREGS) (Wilcox, 2022) . The project is intended to make an impact for many commercial and recreational users by supporting the development of marine technologies while preventing a collision at sea and maintaining the safety of waterways. It provides an opportunity to help identify and design a solution for the threats to our oceans and the transoceanic shipping industry, as well as to sustainably lower the cost and human risk related to the data it collects, future autonomous vessels, lengthy voyages, vast distances, and challenging conditions.

Figure 15. Mayflower Autonomous Ship (Source: Shams, 2021)

The Mayflower Trimaran hull is made of Aluminum, a durable composite building material. It uses solar and wind to generate electric energy. Thanks to its current image processing technology, it has IBM computer vision system technology that can recognize potential threats like cargo ships, fishing vessel, and even partially submerged shipping containers floating in water. This relies on the Automatic Identification System (AIS) of the other ship's class, weight, speed, cargo, etc. (Shams, 2021). With the help of the GPS navigation system, it is able to set its current location, direction, and route after receiving particular information about it. Although the Mayflower had a planned course, the weather can be often unpredictable. The IA captain reads a new route, makes the necessary alterations, and then varies its course according on the circumstances at hand. An AI captain operating on edge computing technologies and connected to the IBM cloud steers the ship (America, 2010). It uses a combination of data and decision-making to identify and avoid other vessel and ocean hazards.

4.5.2. Roboat III Autonomous Surface Vessel

Amsterdam is one of the cities that has taken important steps in the smart cities concept and produced technologies integrated into the existing city structure. The city's canal networks are used for various purposes such as entertainment and tourism and provide the movement of thousands of people. In addition to movement, although it is a bicycle friendly city and has the lowest inhabitants vehicle population, (Duarte et al., 2020) the city has traffic and carbon emission concerns. As the automobile has become dominant in cities around the world, canals have been transformed to tune the city into a new transportation system primarily motivated to alleviate traffic congestion in the city(Peter Cox and Till Koglin, 2020).

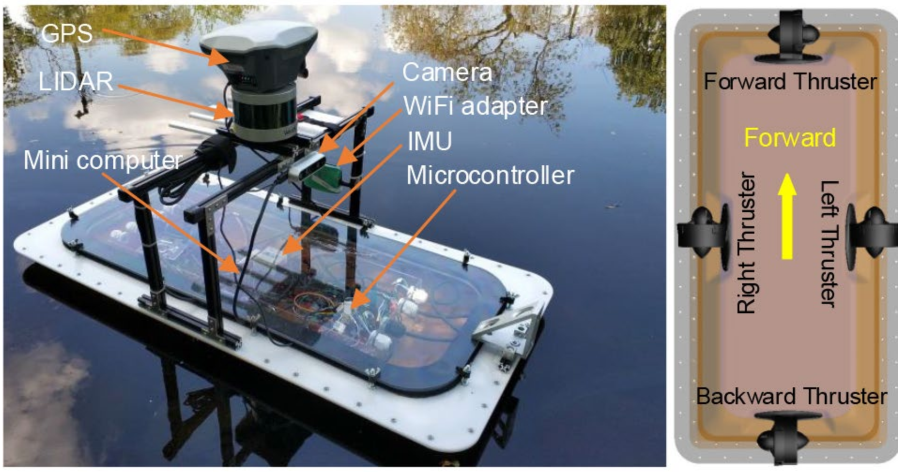


Figure 16. Roboat I: An Autonomous Robotic Boat (Source: Wang et al., 2019)

The Roboat research project, a project of the Amsterdam Institute for Advanced Metropolitan Solutions (AMS Institute) and research carried out by MIT, Delft

University of Technology and Wageningen University and Research ,focus on an autonomous vessel in these canals of Amsterdam and discover the potential and benefits such as reducing traffic, waste and transport portfolio, for both people and goods (Duarte et al., 2020). The project reveals its vision of how autonomous vessel can transform a city with a historical texture like Amsterdam. While The Roboat (Figure 16) senses water, air quality, and environmental factors, it serves the city and defines new areas such as bridges and stages by enabling the self-assembling of urban infrastructures. In addition to drawing a low-carbon transport model, autonomous vehicles (AV) are helping to develop more active and organized travel and enabling mobility that is sensitive to the city's infrastructure and people's needs. This autonomous vessel interacting in urban spaces and smart transportation systems likely to become an important aspect in the future which may change current transportation system (Nagenborg, 2020) can impact the accessibility of education, work, or health care.

The Roboat project developed by MIT's Senseable City Lab for the Amsterdam canal is an important example of responsible urban vessels. The RoBoats (Wang et al., 2019) (Figure 17)can monitor the city's waters using new environmental sensors that provide vital information about the city and human health, can be used to transport goods and people, and have the potential to use self-assembled bridges and concert stages to create temporary embankment infrastructures (Benson, T., van Dijk, S., Batty, 2021) . It offers a new mobility system to the urban environment which is a part of the building environment

Figure 17. Roboat III Autonomous Surface Vessel. (Source: Roboat, 2022)

Within the MIT Sensible lab, possible areas that will serve along the channel have been reported by network analysis, determining strategic points, and mapping the city to evaluate alternatives. According to these data, it is predicted that autonomous ships can eliminate at least some of the 3,500 trucks and 25,000 pickup trucks in Amsterdam(Duarte et al., 2020), as well as contribute to the road traffic due to its low emission strategy(Teekamp, 2016).

In the city of Amsterdam, which has narrow and winding street networks, garbage trucks, especially in the central districts, collect the garbage thrown on the sidewalk, and in this case, it often creates traffic jams. Researchers at MIT have developed a strategy to collect household waste in a more efficient, cleaner and more efficient way with a few robotic ships for garbage collection in the historic center of Amsterdam. The autonomous ship Roboat also offers a waste collection system (Figure 18) for household waste(Duarte et al., 2020), construction waste, can collect garbage bags left on the curbside by using autonomous vessels without hindering pedestrians and cars. As the autonomous ship could become a key area for collecting data on waste and consumption, this data in turn could model other "urban data scientists" based on feedback from robotics and designers identifying the best places.

Figure 18. Roboat Waste Collection System (Source: Roboat, 2022)

4.5.3. WasteShark

An innovative concept called WasteShark (Figure 19) was developed by RanMarine Technology to remove both solid and liquid garbage from the surface of the ocean, with a focus on ports and marinas. RanMarine is Start-up company that combines science and technology to maximize the potential of the oceans and seas for the marine and maritime sectors while preserving the environment and adjusting to climate change (Prof. Dr. Dr. h.c. Frank Kirchner, 2018)

The project's goal is to increase the use of marine resources in a sustainable manner as well as the effects of the world's oceans and seas on human society and economic development. WasteShark, the product of RanMarine, the first prototype of which was developed in the Netherlands, is a product that can autonomously or remotely collect surface waste in ports and marinas with a garbage collection capacity of up to 350 kg at a time and a zero-emission electric compact design and can operate for 16 hours (Wevolver, 2023).

Figure 19. WasteShark (Source: RanMarine, 2023)

In addition, with its small and compact design, it is a model that effectively addresses marine waste caused on by plastic, trash, algae, and other waste in lakes and ponds and makes a surface cleaning procedure easier and more effective in hard-to-reach locations (Prof. Dr. Dr. h.c. Frank Kirchner, 2018). In addition to collecting trash, WasteShark has sensors (Figure 20) that enable it to gather information about the environment. The equipment, which measures depth, temperature, and water quality as well as conductivity, pH, and other environmental sensors, has dimensions of 1556 mm in length, 1078 mm in breadth, and 450 mm in depth. Oxidation-Reduction Potential could also be introduced to the product as an option, and the system may transfer the current data to cloud reporting (RanMarine, 2023). It draws a lower cost (less maintenance and manual labor) model compared to conventional water surface cleaning activities currently performed.

Figure 20. The Wasteshark in Action (Source: RanMarine, 2023)

Canals and environments with more human traffic such as marinas, ports and shorelines are programmed with GPS points to provide usage service and cover hotspots where waste accumulates, and its path can be programmed and monitored remotely. WasteShark aims to provide this autonomous system with stations located in marinas where it can recharge its batteries as well as collect garbage with certain algorithms.

4.6. Level of Autonomy

The research on classification of autonomous surface vehicles (ASVs) has become increasingly significant with the advancement of these new types of ships. A distinguishing characteristic that may be employed for the classification of UVs is the level of autonomy, which can range from complete automation where humans establish the overarching mission objectives, while artificial intelligence governs control to total, albeit remote, manual supervision by a human operator (Shojaei et al., 2018).

4.6.1. MASS

The consensus among experts is that utilizing fully or semi-autonomous robots as part of structural inspection systems can result in a more economically feasible, secure, and reliable inspection process when compared to traditional visual methods. Several organizations have issued reports and regulations regarding the degree of automation required for autonomous ships(FUKUTO, 2021). The most well-known of these is the Maritime Autonomous Surface Ships (MASS) which published the Regulatory Scoping Exercise (RSE) circular in 2018 with the aim of improving safety and economy. According to the circular, an autonomous ship is defined as one that can operate independently of human interaction. The IMO has recommended other levels of automation based on the RSE circular. It has been proposed that the control and responsibility of automated operation should ultimately belong to a human even on fully automated ships, and that the autonomous system should have supervisory control in order to be socially and ethically acceptable.

4.6.2. SHERIDAN SCALE

The concept of the interaction between humans and machines, as defined by Sheridan (Sheridan, 1992), has been a topic of frequent discussion. ASV emphasizes the information processing and action of vehicles based on four control concepts: information collection, analysis, decision selection, and action implementation. This involves continuous monitoring of the environmental surroundings, data detection and analysis, algorithm creation and evaluation, and decision-making. According to Sheridan's scale (Table 3), the Level of Autonomy (LOA) ranges from Level 1, where humans are responsible for all decisions, to Level 10, which is a fully automatic system.

Table 3. Automation levels according to Sheridan (Source: Sheridan, 1992)

Automation level	Definition
1	The human operator performs all tasks without support from the control system.
2	The system offers a complete set of action alternatives, and the operator selects and executes one of those alternatives.

Table 3 (Continued). Automation levels according to Sheridan (Source: Sheridan, 1992)

3	The system suggests a small number of effective action alternatives to the operator. The operator decides whether to execute one of the small number of alternatives or not, and the action is executed by the operator
4	The system offers one suggestion to the operator. The operator decides whether to execute that suggestion or not, and the action is executed by the operator.
5	The system suggests one the most effective action to the operator. If the operator approves the suggestion, it is executed by the system
6	The system offers one suggestion to the operator. If the operator does not veto the suggestion within a certain time, the system executes that suggestion.
6.5	The system presents one suggestion to the operator, and simultaneously executes that suggestion.
7	The system decides and executes all actions automatically and informs the operator of the actions taken
8	The system decides and executes all actions automatically and informs the operator of the action taken if requested by the operator.
9	The system decides and executes all actions automatically. The actions executed are reported to the operator only if the system judges reporting to be necessary
10	The system decides and executes all actions automatically

4.6.3. Lloyd's Register

Although ASV classifications are discussed by Lloyd's Register (Lloyds Register, 2019) , they are defined by building upon continuous improvement. While these definitions define 3 main tasks as making decisions, taking action, and handling exceptions, they emphasize the importance of cyber security by evaluating the hacking of the communication system as a great risk. In order to consider the autonomous solutions, government and initiatives needs to verify safety/security and costs of safe development.

4.6.4. SARUM

Determining the autonomous levels of autonomous unmanned vessel, (Table 4) SARUMS is to provide a security framework for unmanned ships that recognizes their operational use, legal status and the needs of navies according to their mission statement. (European Defense Agency). According to the studies suggested by SARUMS (Safety and Regulations for European Unmmaed Maritime Ststems), autonomy levels are evaluated over 6 levels (Omitola et al., 2018).

Table 4. Sarus Regulation (Source: Omitola et al., 2018)

Automation level	Definition
Level 0: Manned	
Level 1: Operated	It is a level where there is a manned operator and all decision-making mechanisms are completely human. Today, this level is used as a level where electronic navigation aids such as ECDIS, AIS and ARPA are used.
Level 2: Directed	As in the 2nd level, the decision-making authority is still with the human, but it offers solutions to the electronic systems she uses and the probability of human error decreases a little more.
Level 3: Delegated	At this level, the ship control authority is written, there is a captain on the ship and, in the absence of a critical situation, the ship can manage itself.
Level 4: Monitored	The requirement for a human operator on board is removed and the ship can access all sensors and devices, completely remote control, from the onshore office. When not connected to the ship, the ship is in a self-controlled position.
Level 5: Autonomous;	The system suggests one the most effective action to the operator. If the operator approves the suggestion, it is executed by the system

CHAPTER 5: DOUBLE DIAMOND MODEL AND DESIGN THINKING IN THE PRODUCTION PROCESS

The majority of the products produced and developed specifically for use in daily existence have a strategy that concentrates on addressing a certain problem. Design thinking (Dam and Siang, 5AD), allows for flexible adaptation of capacities from specific problems to openings, generalizations, and other problems. In this context, bringing new approaches, managing and testing such processes, and developing new frameworks through idea development techniques based on design thinking are all significant components of effective design. Outlining the current procedure, it is a method that directs designers, making the design process more definite than a complex system. Design-oriented thinking suggests designers solve complex problems by producing more than one solution through synthesis, which deals with the solution of chaotic problems. It defines design-oriented thinking as transforming different ideas from engineering and design into multiple reasonable solutions (Cross, 2021). Designers must remain updated with advancing technologies. Developments in innovation are also tightly connected to changes in design, where new technology, new markets, and new organizational structures in business lead to the creation of new circumstances that push for new design methods and principles. However, it has a broad range of applications, including managing between various professions and fields (finance, market and design). The structure of teams and the management of the product and service model that will reach the end user are also included in design management. In addition to that, it also involves management of communication between users, institutions, and representatives. Management refers to planning, directing, and overseeing a process (DuBrin, 2011). A key factor in successful design management is how the teams, processes and procedures involved in a project are organized, coordinated and executed. Efficient time management, risk management, and team motivation is important for a successful project output. It exists almost everywhere in our daily lives, in a wide variety of contexts linked to society, the environment, technology, politics, and the economy. Design is in the role of an interpreter, collaborating between different disciplines, bridging technological research and innovation and their application to social practice(“Beyond net zero: A systemic design approach,” 2021).

5.1. Double Diamond Model

Due to the complexity that this rapid movement brings, it is necessary to have a flexible process infrastructure that can respond quickly to changes in society, business, and technology. As a result, considerations such as sustainability, legislation, security, social responsibility, and others must be made during the design process (Council, 2007a). The "Double Diamond Method", (Figure 21) which is a product and serves-centered design process, is a design management that is generally applied in the organizational environment. The goal and outcome are achieved by a series of actions or processes that adhere to a predetermined set of rules, even if this process is a design process that is widely understood, taught, and used (Best, 2006). Alternatively, it offers formulas and diagrams to map the process, ensuring that it can be implemented correctly and assisting the designer and other stakeholders in accomplishing their goals. An essential component of the design process is establishing interaction between designers and various disciplines and defining roles. Turner (Turner, 2001), explains that a "role" is a group of actions and attitudes that are crucial for maintaining business continuity and are thought to belong together. The design process (Best, 2006), procedure, sequence of specific events, actions, or methods used to achieve the goal, goal, and result enable interaction between different disciplines and the production process. The Double Diamond model expands on our existing innovation framework by highlighting the context in which it operates before seeking the solution as a key component of the systematic design process, recognizing its complexity in production, and providing people and the environment equal value (“Beyond net zero: A systemic design approach,” 2021). The Double Diamond model is an integral part of the design process and proposes that it should consist of four phases: Discover, Define, Develop, Deliver. These methods assist and provide guidance in mapping and planning the design process.

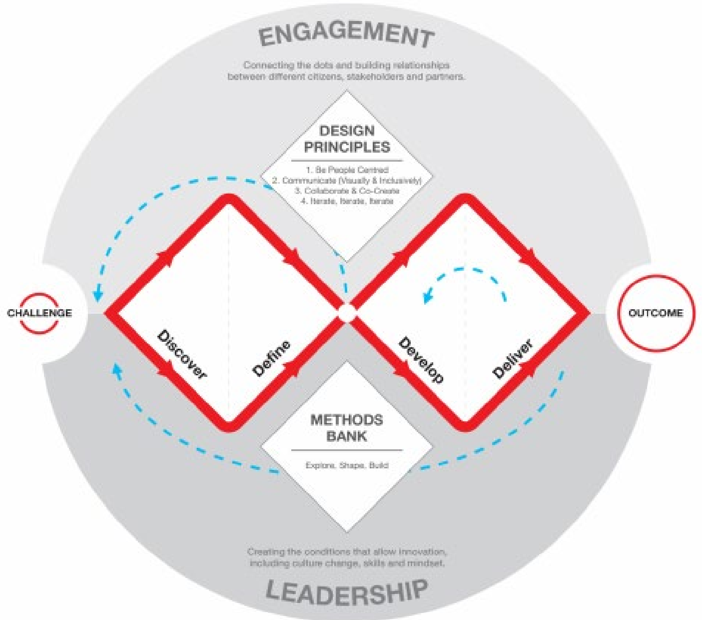


Figure 21. Double Diamond Diagram (Source: Council, 2021)

5.1.1. *Discovery:*

The first stage is the thinking stage and presents the beginning of the project (Suoheimo et al., 2022) that designers prepare themselves for the research and about specific topics. Designers in this stage identify the basic hypotheses and requirements while also researching into the initial problem underlying cause(Gustafsson, 2019). It takes a broad perspective on the subject with the intention of producing innovation. It identifies opportunities at an early stage and identifies anticipated outcomes and uncertainties at an early stage (Gustafsson, 2019). This preliminary research situation of the design process can pivot the ideas of the designers or strengthen the values they create. At this stage, start-ups evaluate their potential opportunities and weaknesses at this stage and make the production process more effective by truly understanding the market demands at the production stage. Designers should fully comprehend the root of the problem, identify its underlying causes, and employ solution-focused strategies throughout the design process while taking into account the concepts and materials that already exist and that we may draw from ("Beyond net zero: A systemic design approach," 2021). Finding the correct problem and right solution is a crucial components within this process which leads engineers and designers to clear emphasis on researching the problem and create solution (Norman, 2013). Designer should be able to articulate the problem statement, guide to whole team in this process.

5.1.2. ***Define***:

The Define stage is where they transform, evaluated, and examined in the Discovery stage into a project brief suitable for their interests in line with a certain aim (Gustafsson, 2019). In this phase, it prepares for development using design methods such as brainstorming, visualization, prototyping, testing and scenarios, and enters the prototype development phase, enabling the final product and service (Council, 2007a). It reviews and filters idea data in Discovery, analyzes findings, and prototyping by presenting refined solution ideas. Doppelt (Doppelt, 2009) described the design process as defining the problem and identifying needs, designing/developing and evaluating a prototype.

5.1.3. Develop:

At this stage, it is now prepared for development using design methods such as brainstorming, visualization, prototyping, testing and scenarios, and enters the prototype development phase, enabling the final product and service (Council, 2007a). The define created definition phase makes it possible to plan the product and service, thus speeding up the process and making it possible effectively. Before investing funds and resources to the final delivery stages, prototyping is an essential step in the design process for testing, analyzing, and optimizing new ideas (Best, 2010). By making the product and service of existing production tangible at an early stage, collaboration and improvements in the development phase with the end user help reduce risk.

5.1.4. Deliver:

At this stage, the concept has been final tested and is in its launch phase. Opportunities and problems of the product are identified and tested with user feedback and used to identify new ideas and modifications.
This typically involves scrutinizing the product against regulatory and legal standards, conducting damage and compatibility tests. During this stage, organizations also utilize the opportunity to evaluate the impact of the design on customer satisfaction, with the aim of quantifying the value of effective design for the brand (Council,

2007a). All the companies involved in the study took their responsibility to establish feedback loops very seriously. This practice was regarded as a means of continually enhancing the product which each company adopted a unique approach, the underlying lesson is apparent. Once the product is in the market, it becomes crucial to attentively listen to users and ensure that their perspectives and opinions are incorporated into subsequent iterations of the design (Council, 2007b). Thus, rather than focusing solely on launching the product swiftly, one must prepare for a continual journey of improvement.

CHAPTER 6: CASE STUDY

6.1. Problem definition

It is very difficult for manned ships to conduct research and measurements in shallow water areas, for example, in reservoirs, streams, lakes and ports. Manned vessels are not flexible enough to collect complete data and surveyors have to collect data. Manned vessels cannot enter most shallow water areas and near shore, otherwise there is a risk of running aground and damaging survey equipment. In addition, it is difficult to maintain the same survey route each time and the distance between each survey line is large. The manned vessels cannot reach a specific inspection area, which can cost a lot of time and labor to move the vessel to the target point. Manual maintenance surveys on uncertain water areas can pose threats to personal safety. At the same time, measuring in the area of dirty water can be dangerous to the human body. Bathymetric surveys of tailings dams are important because the submerged pond bottom is constantly changing and so is the water volume storage. Local authorities may also require mining companies to submit a Residual Storage Facility water capacity report.

The low-draft autonomous vessel is suitable for working in shallow areas. Its lowest draft is 25 cm, allowing working and researching in shallow waters where large ships cannot enter. It helps to collect data for constructing and developing structures near water or underwater. Being small and compact, it can be used in non-navigable water areas such as reservoirs and some inland rivers. Autonomous Water Surface Cleaning Vessel reduces in Labor cost and research can be easily done by two people rather than a group of workers. Incomplete data collection and poor data accuracy are the inevitable shortcomings of manned ship survey.

6.2. Methodological Background

The project's primary goal is to assess the design, production, and potential applications of a vessel that will help in the creation of an autonomous waste collector vessel that can safely locate, inventory, and then collect floating waste in dynamic marine environments. The project will be carried out by a team of 4 different disciplines; Designers, software and computer engineers, and marine engineers. During the examination of the small autonomous ship, all possible concepts on the subject; machine learning algorithms, necessary hardware and software, vessel design and performance, compatibility with the city and the environment, and sustainability will be investigated.

The objective is to develop a modular design strategy, create a product that is lightweight and portable, and lower the cost of the marine environment cleaning process in order to implement the solution on a large scale. This robot comprises of a conveyor-belt system that gathers and removes floating waste from the ocean, including plastic.

6.2.1. Outputs and Usage Areas

It is planned as a smart water surface vehicle to automate the services of zero emission, solar powered, efficient, artificial intelligence supported, self-driving, autonomous surface vehicle. The autonomous vessel project was born from the idea of how and how it can promote the reallocation of urban infrastructure and the marine environment.

Compared to manned water surface cleaning vehicles, Autonomous Water Surface Cleaning Vessel aims to perform services including cleaning the sea surface wastes, surface oil, and foam in shallow water locations. Develop an electric-powered solution that employs artificial intelligence (AI) to locate and collect garbage in shallow water locations inaccessible to manned vessel while also saving time and fuel and worker safety risks in vessel, lakes, canals, rivers, ponds, and port areas. It intends to provide a portable, lightweight, and small product service while building a garbage pickup robot.

It provides a service opportunity that allows autonomous or remote cleaning of surface wastes in a completely safe way in areas close to boats in ports and marinas, in pontoon areas and in areas where it is difficult for the user to reach. Marine waste caused by the streams flowing into their marinas, a problem that marina managers face, is considered as a potential area of use for the Autonomous Water Surface Cleaning Vessel.

6.2.2. Technologies and Methods

Autonomous Water Surface Cleaning Vessel may easily perform waste collection manually or autonomously by two individuals instead of a team of workers, with the goal of lowering labor costs. The autonomous ship provides an alternative that can handle garbage in risky marine locations more accurately and safely. As a result of the study performed using the autonomous system, it is now possible to manage sea surface garbage in the operation region more quickly and effectively.

Designing the low draft autonomous vessel is suitable for working in shallow areas. It has a minimum draft of 25 cm and uses a camera and sensor instruments to gather wastes, oils, and foams on the water's surface in shallow areas where large ships cannot enter. It also recognizes and reports objects on the water surface. In close-to-water places like ports, marine, industrial, and shipyard sites, it expedites waste removal at the water's surface. It can be utilized in locations of non-navigable water, such as reservoirs and some inland rivers, because of its tiny size and compact design.

The autonomous ship will operate in an area where there are several challenges, such as severe weather conditions, currents and traffic from other vessels. The autonomous ship will be designed to stop when an obstacle comes in its path. The first stage of ranking is to determine the maximum weight of the evaluation criteria. In order for the ship to meet the stability requirement, it must be strong enough to withstand loads and slopes from different weather and sea conditions.

6.3. Scope

6.3.1. Product and Innovations

Two products come from technological verification activities: First, there is the mobility of the autonomous surface cleaning vehicle to operate by the current operating conditions (Wind, Wavelength, and Current), and then there is the aerodynamic or hydrodynamic design of the thruster propellers for maneuvering, and finally, there is the design of the product ergonomics for easy transport. It will be possible to make Control and Data information, simultaneous image information, and a warning system by developing the second output autonomous software architecture. Additionally, it is intended to adhere to specific Quality Management System, International Maritime Organization, and environmental sustainability criteria.

In addition, our project, which will offer an innovative robotic solution that collects marine litter (waste and oil) from marinas or other coastal waterways (lakes, rivers, canals, etc.), will be easier to use, easier to recognize, electrically and silently to operate. The primary objectives of this project are to clean up the bay, enhance the quality of the air and water, reduce pollution, and provide renewable energy for the port utilizing cutting-edge green technologies. The waste management and pollution are classified with different waste codes and are collected in the waste reception facility. Either a licensed waste reception facility operates or receives services from environmental consultancy firms in order to receive the waste oil and bilge oil produced by yachts and vessels in the marinas.

6.4. Analyzing the Double diamond design process through research & implementation of Autonomous Water Surface Cleaning Vessel Project

The autonomous water surface cleaning vehicle project developed using the Double Diamond design process (Figure 22) examined, analyzed, and discussed in terms of its research, design, applicability, and suitability for this given project. This project, which is being carried out in accordance with the 17 UN Sustainable Development Goals, is directly related to targets 6 (Clean Water and Sanitation), 14 (Education), and

15. (Life below water). In this area, common binding and inclusive areas were identified, and the social and environmental effects of the product to be released were investigated.
A total of 5 different disciplines worked in the project; Designer, Computer Engineer, Software Engineer, Physicist, Naval Architect and marine Engineer;
Rıza Serkan Kaskan; Physicist, Middle East Technical University: He took part in the image processing algorithms, navigation algorithms and hydrodynamic calculations of the Autonomous Water Surface Cleaning Vessel. Within the scope of the project, he took part in the development, calculation and testing of the machine learning and image processing algorithms of the ship and contributed to the performance tests of the boat in the existing production functions by making calculations.
Barış Genco Atakay, Naval Architecture and Mechanical Engineer, Chalmers Technical University: In the project, he worked on the hydrodynamics, Sinking Volume calculation, engine power and thrust calculation, static tests, hull design of the Vatoz.
Oğul Görgülü, Interior Architect and Designer, İzmir University of Economics: Responsible for hull and superstructure design, autonomous software UI, UX design and production of the autonomous boat Vatoz. In this project, Autonomous boat also took part in subjects such as computer-aided service design, boat design, concept development and detail analysis, technical production details and project management.
Umut Kanpalta, Computer Engineer, Izmir University of Economics: He took part in the project on hardware integration, production of autonomous boats and mechanical equipment. He was involved in tasks such as Arduino and sensor development for the autonomous ship in this project, applying the necessary electrical accents, identifying, reporting and manufacturing the necessary hardware for the autonomous boat, providing software hardware integration and testing.
Orhan Eryiğit, Software Engineer, İzmir University of Economics: Along with his work on autonomous software in the project, he worked on the boat's control mechanism, hardware software integration and developing machine learning algorithms with Java and C software. In addition to product development, he shows experience in artificial neural networks, Embedded System Design and Development, Software Development.

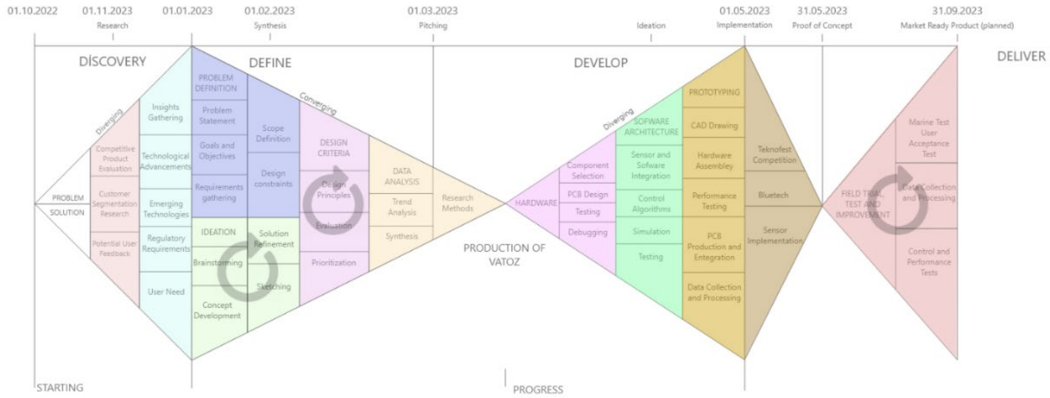


Figure 22. Double Diamond model Timeline

6.4.1. Discover (Research Phase):

The Discovery section of the Double Diamond model was a critical part of our Autonomous Water Surface Cleaning Vessel project, conducted between 01.10.2022 - 01.01.2023. We followed a structured process to gain a comprehensive understanding of the issue at hand, starting with problem and solution, customer segmentation research, competitive product evaluation, potential user feedback, insights gathering, technological advancements, emerging technologies, regulatory requirements, and user needs.

To begin, we conducted extensive research on marine pollution and available technologies for cleaning the water surface, which involved reviewing relevant literature and identifying the sources and impacts of marine pollution. This research confirmed the pressing need for a more economical, efficient, and low-maintenance solution for eradicating marine debris.

Next, we conducted market research to identify existing solutions and potential competitors, which revealed a lack of autonomous water cleaning surface vessels designed for small craft with the same level of autonomy and efficiency that we were seeking. Discussions were also held with key stakeholders, such as the Izmir Marina general manager, the municipalities of Izmir, and yacht owners in the marina regions, to determine the probability of using this product in the Turkish market. The outcome of these discussions confirmed the commercial application of the autonomous boat in waste and environmental management.

We also conducted an in-depth study of available technologies for cleansing the water surface, which revealed the limitations of existing solutions and the need for a vessel equipped with sensors, cameras, and a cleaning mechanism to collect debris from the water surface, as well as an autonomous system to control the vessel's movements and optimize its cleaning operations.

Overall, the Discover stage provided us with a solid foundation of knowledge and understanding of the issue and available technologies, which proved instrumental in delineating the critical prerequisites for our proposed solution in the following phase of the Double Diamond Design Process. The output of this research formed the basis of our application to the Tübitak 1512 techno-enterprise program, which was subsequently approved, allowing us to move forward with the project.

6.4.2. Define (Synthesis Phase):

The Define stage is a critical part of the Double Diamond Design Process, which involves synthesizing the information gathered during the Discover stage to define the problem, requirements, and design criteria for the proposed solution. In the Autonomous Water Surface Cleaning Vessel Project, the Define stage was instrumental in establishing the key features and functionalities of the proposed solution.

The first step in the Define stage was to define the problem statement, which was to design an Autonomous Water Surface Cleaning Vessel (Vatoz) that could effectively gather marine waste while being cost-effective and easy to maintain. Alongside this, the project's scope was established, which encompassed designing the mechanical, electrical, and software systems of the vessel.

During the Define stage, the intended hardware architecture of the vessel was designed, and communication diagrams were created. The hardware connections and software operations with pi were evaluated, including their hierarchies, functionalities, and interconnections. Additionally, several Unity functions were tested, and visualizations of several algorithms such as image processing, ship target detection, control, and navigation were constructed. The libraries to be used were chosen, and their codes were listed until the equipment needed to be acquired. The software architecture's development roadmap was defined, and practical precautions were documented. Artificial intelligence and image processing software and design architectures were investigated. The current product, Vatoz's Bill of Materials (BOM), was revised, and sensor testing was accomplished. A flowchart was created for the interface design after research on the boat control systems.

Furthermore, the locations of the equipment, such as battery locations, microcontrollers, sensors, cable connections, camera, and Lidar, that would be integrated into the product were determined through the plan, and a list of the products to be purchased was made. The drawings of the wiring diagrams (Schematic hardware) of the product's hardware were started.

The next step was to establish the design criteria and requirements for the solution. To accomplish this, the vessel's size, shape, and material requirements were defined to ensure its durability, stability, and maneuverability. The Buoyant Force, Ship Resistance, Hull Design Analysis, Engine Power Calculation, Drag Force, and thrust simulation tests of the designed vessel were carried out. Several design concepts were developed and evaluated based on their feasibility, cost-effectiveness, and ease of maintenance. Physical and digital prototypes were then created to test the vessel's functionalities and refine the design formation.

In addition, the technical requirements for the vessel's electrical and mechanical systems, including the propulsion system, the cleaning mechanism, and the sensor and camera system, were established. The software requirements for the autonomous control system, which included the path planning and obstacle avoidance algorithms, were also defined.

Overall, the Define stage was crucial in defining the problem, requirements, and design criteria for the proposed solution. It provided a clear direction for the project, enabling the team to move forward with confidence and purpose.

6.4.3. Develop (Ideation Phase):

During the develop phase of the Autonomous water surface Vessel project, Vatoz, a systematic process following the double diamond model was implemented. The key steps involved in this phase include component selection, PCB design, hardware testing and debugging, sensor and software integration, control algorithms simulation and testing, and prototyping.

Component selection was performed in the hardware section to identify and choose the most suitable sensors and other hardware components in accordance with the project requirements. The selected components were then integrated into the overall system. The PCB design played a crucial role in the hardware development process. This step involved meticulously placing the chosen components on the PCB and ensuring appropriate power and sensor data connections. To ensure the proper functioning of the Vatoz system, hardware testing and debugging activities were conducted. This phase involved verifying the functionality of the hardware components, addressing any identified issues or errors, and ensuring the overall operation of the Vatoz.

The software architecture aspect focused on the integration of sensors and software. This involved establishing the necessary connections between the sensors and the system, as well as developing software interfaces to capture and process sensor data effectively. Control algorithms simulation and testing were carried out in the software architecture part. This involved the development and refinement of control algorithms governing the movements of the Vatoz. The Prototype of the GUI (Graphical user interface) of the Navigation system was designed and implemented. The performance of these algorithms was then tested in a simulated environment to ensure their effectiveness and efficiency.

A prototyping phase was executed to create a physical prototype of the Vatoz. This involved activities such as creating CAD drawings for the design, assembling the hardware components, conducting performance testing to verify functionality, and integrating the PCB into the prototype. Additionally, data collection processing was implemented during this phase to gather relevant data for further analysis and improvement.

The development phase of the Vatoz project adhered to the double diamond model and encompassed essential steps including component selection, PCB design, hardware testing and debugging, sensor and software integration, control algorithms simulation and testing, and prototyping. These activities were vital in refining and advancing the Autonomous Water Cleaning Vessel, Vatoz, before proceeding to subsequent phases of the project.

6.4.4. Deliver (Implementation Phase):

In this phase, roadmaps were determined for conducting proof of concept activities. These roadmaps outlined the necessary steps and activities required to validate the feasibility and functionality of the Vatoz project. The team actively participated in initiative events such as Teknofest competition and Bluetech. These events provided opportunities to showcase the Vatoz project, gather valuable insights from industry experts, and receive feedback from potential customers and users.

Before the Vatoz product was launched into the market, user feedback was collected and carefully evaluated. This feedback helped in refining the product by better defining the problem statement, identifying areas for improvement, and incorporating user suggestions for add-ons and enhancements. An agreement was made with Izmir Marina to conduct field tests. This agreement allowed for the collection of real-world data, as well as the testing and evaluation of the Vatoz system's control and performance in an actual marine environment. As part of the field test agreement, data collection, control, and performance tests were planned and conducted. These tests aimed to validate the functionality, reliability, and performance of the Vatoz vessel system, ensuring its readiness for market launch.

Overall, the deliver phase of the Double Diamond design model involved establishing roadmaps for proof of concept, participating in initiative events, evaluating user feedback, and conducting field tests with the collaboration of Izmir Marina. These experiences and tests contributed to refining the Autonomous Water Cleaning Vessel, product and ensuring its effectiveness and suitability for the target market.

6.5. Methodology: Prototype Design of Autonomous Water Surface Cleaning Vessel

To address this goal, we opted for a catamaran design solution to fulfill our needs. We chose this design because of its intrinsic shape stability, high operational efficiency, and low draft—Autonomous Water Surface Cleaning vessel composed of the following modules.

6.5.1. Establishing the Design Criteria and Requirements

6.5.1.1. Hull and Superstructure Design

The hull and superstructure design of the Vatoz product was developed by analyzing the semiotic and taxonomic design elements of the sea creature after classifying and organizing its physical, motion, and sensory characteristics. Design and functional features were added to the physical and movement structure of the Vatoz to create a final design that includes a balanced hull calculation required for the catamaran-type design. 3D modeling (Figure 24) of sketch drawings (Figure 23) and design of integrated parts were made.

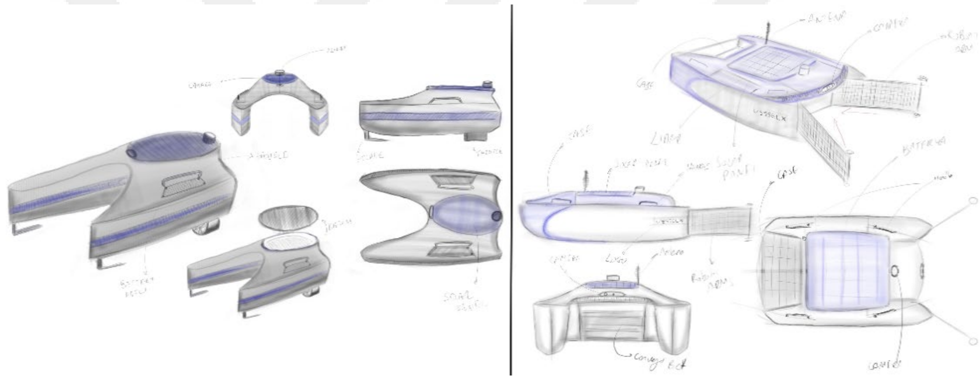


Figure 23. Sketches in the Design process

The product is equipped with 1 motor in each body and 2 brushed dc motors in total, which can move independently of each other and rotate 360 degrees wherever they are, making it easy to use in narrow areas. To ensure it can overcome the force and move effectively, the thrust force acting on the propellers was calculated and analyzed. It was then planned to be produced in blocks from the 3D printer and coated with Fiberglass glass fiber to make it lighter and more flexible. The waterproof and impermeable hatch covers were designed to protect the integral hardware, with cables connected using waterproof connectors and records.

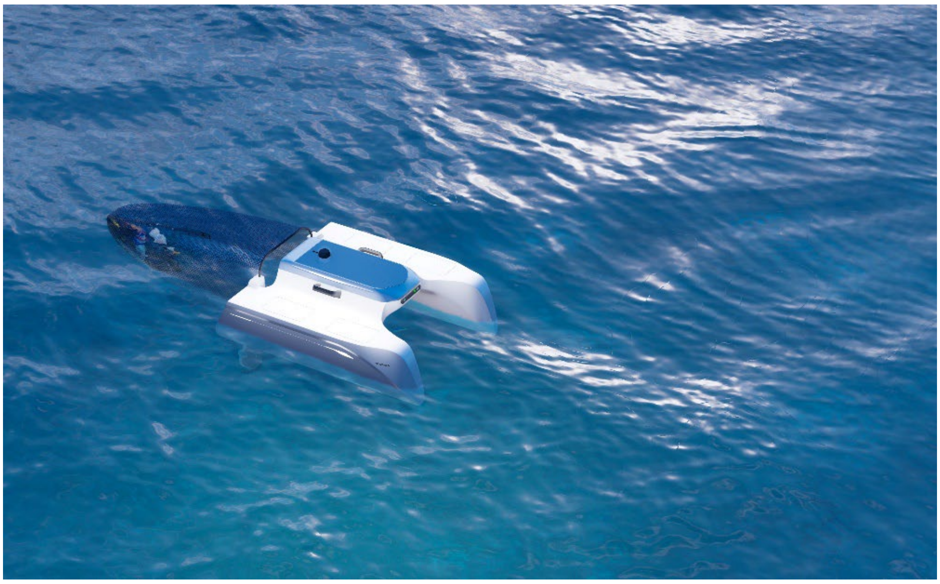


Figure 24. Vatoz operation Render

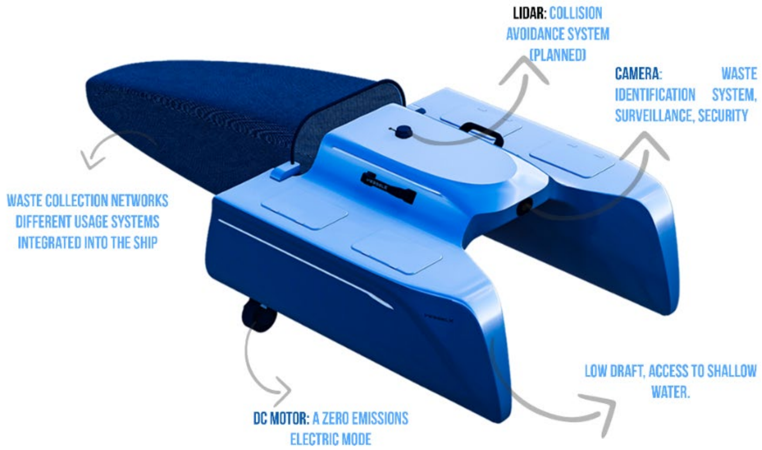


Figure 25. Overall features of Vatoz

The project focuses on six key aspects (Figure 25): waste collection, easy portability and usability, autonomous operation, absence of polluting emissions, low draft capability, and water quality monitoring. Through an academic lens, this research provides a comprehensive analysis of Vatoz's influence in these areas, highlighting its potential (Figure 26) to address environmental concerns and enhance operational efficiency.

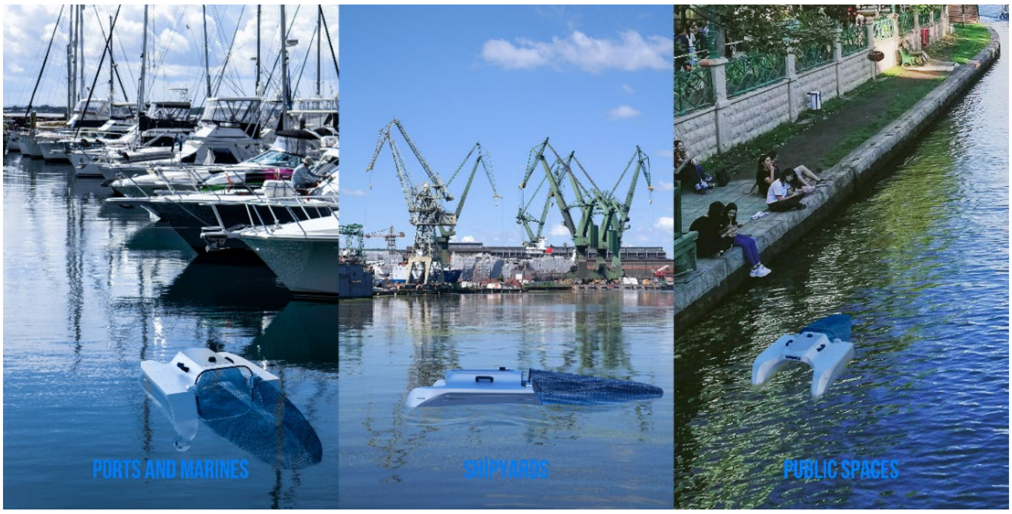


Figure 26. Potential usage of Vatoz

Utilization Service in Ports and Marinas:

One of the primary applications of this project is in ports and marinas, where it planning to offers a unique service opportunity. The autonomous or remote cleaning of surface wastes in areas close to boats, pontoon areas, and other hard-to-reach places provides a safe and efficient solution. By utilizing advanced technology, the project ensures that waste materials such as oil, debris, and other pollutants are safely collected into a material network. This service not only helps maintain the cleanliness of the marine environment but also reduces the manual labor required for waste collection.

Industry and Business Sites Usage Service:

The potential for utilizing this project extends beyond ports and marinas. Industries and business sites can greatly benefit from the autonomous waste collection service it offers. The project's technology allows for the safe collection of oil, waste, and debris from the sea and their containment in a material network. This service ensures the effective management of industrial waste, helping companies adhere to environmental regulations and maintain a clean and sustainable operation. Moreover, the project's remote capabilities make it suitable for accessing and collecting waste in areas that are difficult for users to reach manually.

Usage Service in Shipyards:

Shipyards are another segment where this project holds immense potential. With the ability to autonomously or remotely collect industrial waste and handle accidental spills, such as hydraulic fluid, fuel, paint, and micro-waste, the project offers a reliable and efficient solution. The advanced technologies employed in the project ensure the safe containment and disposal of hazardous materials, reducing the risk of environmental contamination and improving overall safety standards within shipyards. By streamlining waste management processes, shipyard operations can become more environmentally friendly and sustainable.

The project's Autonomous Surface Water Cleaning vessel, Vatoz, capabilities present significant usage potentials in various segments, including ports and marinas, industry and business sites, and shipyards. By offering a safe, efficient, and reliable solution for waste management, the project contributes to maintaining clean and sustainable environments. Its ability to operate autonomously or remotely in hard-to-reach areas makes it a valuable asset in the maritime industry. As industries and businesses strive to minimize their environmental impact, the adoption of this project can pave the way for a more sustainable future.

Waste Collection:
Vatoz effectively addresses the issue of waste collection by implementing a strategy that involves reducing oil and floating waste before disposing of it in the open sea. This approach not only contributes to environmental preservation but also promotes sustainable waste management practices.

Autonomous Operation:
The technology behind Vatoz enables it to operate autonomously within a predefined area or be remotely controlled. This feature offers distinct advantages, including improved operational flexibility, reduced human intervention, and enhanced productivity.

Low Draft:
Vatoz's ability to operate in shallow water areas is a remarkable achievement. This characteristic expands the range of water bodies where waste collection and monitoring activities can be carried out. Consequently, previously inaccessible or challenging environments can now be effectively managed and monitored.

Easy to Carry and Use:
Considerable attention has been devoted to enhancing the working conditions of both staff and users. Vatoz's design prioritizes easy portability and usability, ensuring that the device is convenient to carry and operate. This development has positive implications for overall user satisfaction and efficiency in waste management operations.

No Polluting Emission:
Vatoz's integration of electric batteries allows it to achieve zero emissions during its operation. By eliminating polluting emissions commonly associated with traditional waste collection methods, Vatoz significantly contributes to mitigating environmental pollution and promoting sustainable practices.

Water Quality Monitoring:
In addition to waste collection, Vatoz also incorporates a water quality monitoring system. This feature enables continuous monitoring and improvement of water quality, ensuring that pollution levels are effectively managed. By providing real-time data and insights, Vatoz empowers stakeholders to make informed decisions regarding water resource management.
The physical structure of the ship is depicted in, consisting of the catamaran hull fixed to the port and starboard side, providing the buoyancy of the ship. The central box houses the onboard electronics responsible for the navigation units, including sensors and microcontrollers. The other two bodies have four 12 V 24 Ah batteries with a total weight of 23,040 kg or Li-Ion batteries with the same values. Below is data about the ship. These data are values taken when the garbage bag is empty, and the target upper carrying limit is 65 kg. Stability, strength, and resistance calculations required to optimize the current design were made in the simulation environment.

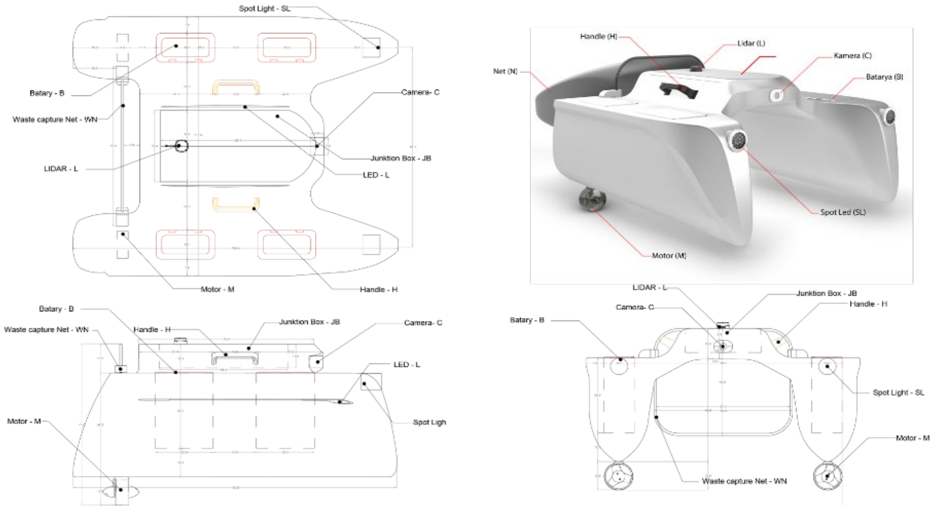


Figure 27. Vatoz Technical Drawing

The determined physical parameters (Table 5) and weight balance of the equipment on the boat were then used to create a pre-fiber mockup with the carcass system to be made on the plywood to be drawn, together with the equipment of a boat (Figure 27). The skeleton of the boat consists of 3 different parts, including the Transverse Frame consisting of Posts, Sheer Strake (Handrail), and Keel (spine), as well as Asf (Stern) and upper part. With 8 posts, 22 handrails, 2 keels, 2 keels, and 1 upper part, a total of 35 parts were drawn with joint details.

Table 5. Physical Parameters of the Vatoz

Parameters	Value
Vessel Length	140 cm
Waterline Length	136 cm
Beam Overall (BOA)	120 cm
Multi Hull Beam Centerline (BCL)	89.50 cm
Draft	0.165 m
Depth	60.50 cm
Volumetric displacement	0.07 M3
Displacement	71 Kg
Wetted surface	1.17 M2

6.5.1.2. Ship Performance and Test Analysis Simulations

Vessel design and simulation environments have become an essential part of modern-day engineering. In order to create a realistic simulation environment for a vehicle, accurate calculations of total resistance are required. Lower values of total resistance were calculated analytically, taking into consideration the size, design, and speed of the vehicle. In fluid mechanics, the Froude number (Inertia/Gravity) was used instead of the Reynolds number (Inertia/Viscosity) to create realistic values in the simulation environment. The Froude number approach is more accurate because it considers the size, design, and speed of the vehicle. The Froude number is calculated using the equation $F_n=U_\infty/\sqrt{gL}$.

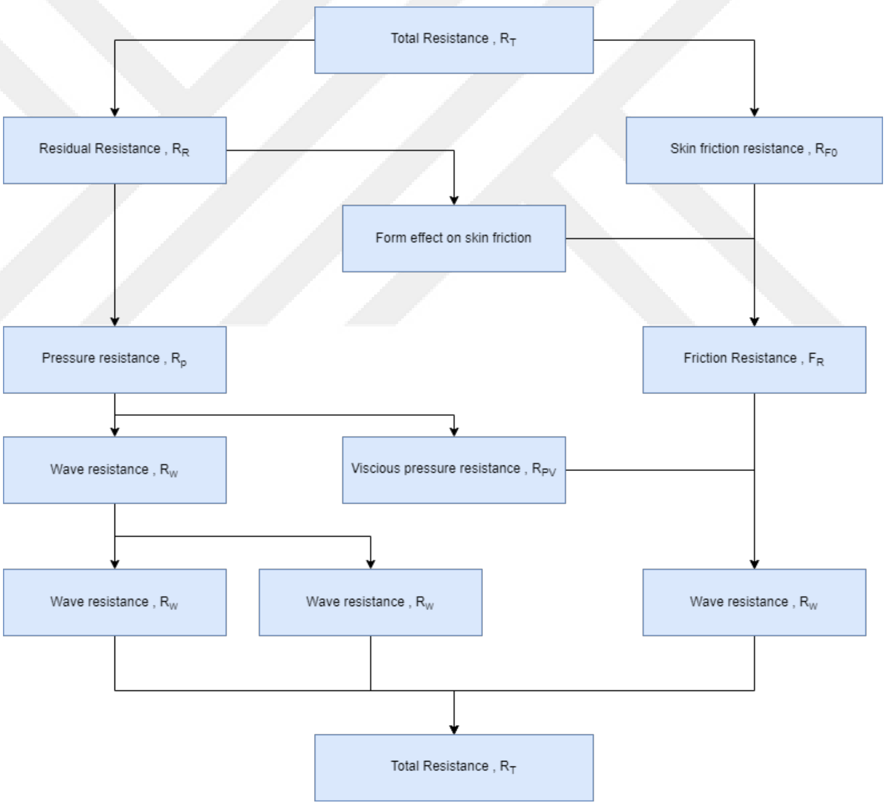


Figure 28. Iterative resistance calculation

The coefficients used in the ship's general pressure related data depend on the size and speed of the ship. The free surface boundary conditions are linearized, and the Kelvin free surface condition is used. The pattern formed by the Kelvin waves is analyzed according to the velocity relationship proposed by Froude, and the margin of error is reviewed. Analytical solutions were used instead of the proposed numerical analysis due to the Vatoz's different body structure. The wave potential theory formed by the Airy wave theory was used as the basis for these solutions.

Standard GZ calculations were used to make static and stabilization calculations, while trim and stability calculations were calculated from the same theories. However, the prototype needs to be examined over a longer period of time for detailed information. The total resistance, speed, and graph of the vehicle were created as a result of static and dynamic calculations. The graph of power and speed emerges from this graph.

Accurate calculations of total resistance are essential for creating a realistic simulation environment for a vehicle. The use of the Froude number approach in fluid mechanics is more accurate than the Reynolds number approach, as it takes into consideration the size, design, and speed of the vehicle. Analytical solutions based on the wave potential theory were used to analyze the Vatoz’s different body structure. Standard calculations were used for static and stabilization calculations, while trim and stability calculations were calculated from the same theories. The prototype needs to be examined over a longer period of time for detailed information.

6.5.1.3. Hull Design Analysis

The catamaran-type ship has been chosen due to its high stability, and the area between the two hulls is used for garbage collection. The asymmetrical structure in the front of the two bodies has been given a sharper angle to facilitate the intake of water, which will help in the transfer of the garbage to the waste bag. The gradually increasing angle of the hulls facing outward from the center of the ship is designed to increase their maneuvering and movement capabilities and to optimize the fluid flow during the maneuver. The superstructure that connects the hulls of the ship has a thin structure to break the air resistance and is placed by paying attention to the angle of the camera in the superstructure of the ship.

6.5.1.4. *Ship Resistance Tests*

Table 6. Speed vs Resistance

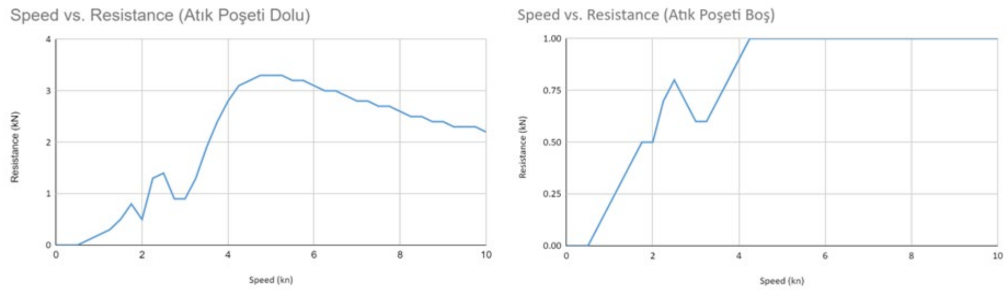


Table 6 shows the speed and resistance table of the ship. The graphs above show the total resistance that the ship will encounter according to the empty and full speeds of the waste net. The values of both graphs are made assuming a highly permeable litter net and assuming that amorphic litter pieces will allow water to pass through. When the garbage net is full, the maximum weight that can be taken is calculated as 65 kg, and calculations are made considering that the garbage will not have its own buoyancy (in the worst case).

6.5.1.5. *Engine Power Analysis*

Table 7. Speed vs Power

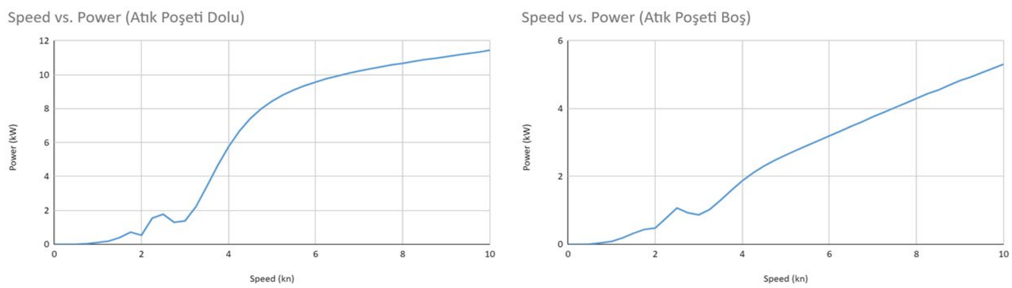


Table 7 shows the speed and power consumption of the ship. In the graphs above, simulations of the expected velocities of the empty and full states of the ship's waste network are visualized. Using the data here, the average power consumption of the ship was calculated, and the average operation time was calculated.

There are two graphs given in the report. One is total resistance and velocity, and the other is required thrust and velocity. The reason why these graphics are given is for the battery and motor details that the product needs. The total resistance consists of the forces encountered by the vehicle. The elements on which the total resistance depends are shown in the diagram below. The hull design, ship resistance tests, and engine power analysis of the catamaran-type ship that can collect garbage from the water have been analyzed in this article. The ship's design ensures high stability, maneuvering, and movement capabilities, and the ship's resistance to movement has been tested to ensure efficient operation. The ship's power consumption has been calculated, and the graphs provided will help in determining the battery and motor details that the product needs. Overall, the analysis of the ship design and its capabilities is promising, and it presents a potential solution to reducing waste in our oceans.

6.5.2. *Developing the Hardware and Software Systems*

6.5.2.1. *General Hardware Components:*

In the software aspect of the autonomous boat, Vatoz, flowcharts (Figure 29) and case diagrams were created to depict the functions, relationships, and hierarchies. Hardware connections and software processes related to Raspberry Pi were examined. Functionality was tested on Unity to visualize the algorithms. The libraries to be used were determined, and library codes were listed until the equipment arrived. The roadmap and actions for the software architecture were defined. Positioning, mapping, and multiple sensors were identified for the estimation of moving and static obstacles. Thruster motors were selected to ensure the maneuverability and efficient travel of the autonomous boat. Two microcontrollers, Arduino and Raspberry Pi, were utilized, with Raspberry Pi serving as the main controller for ship operations and Arduino used for monitoring water quality and reading sensor data. The use of a LoRa module for long-distance data transmission is planned.

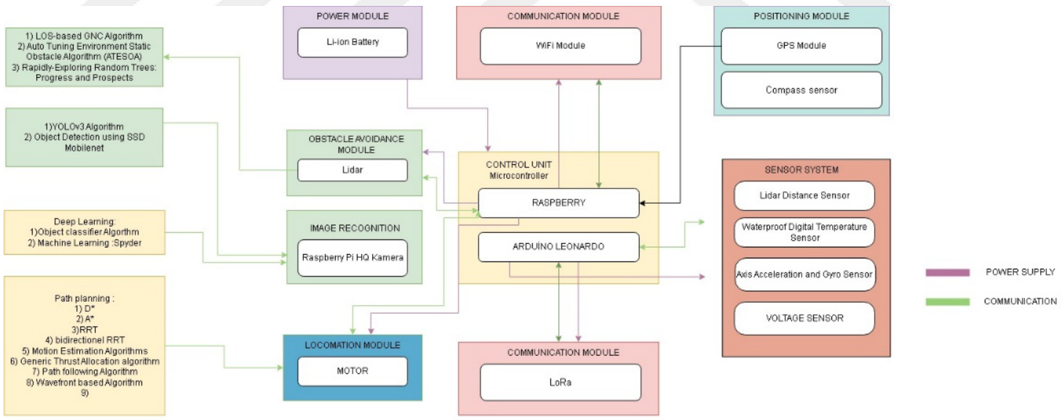


Figure 29. Hardware system architecture schematic

6.5.2.2. Communication Module:

CONTROLLER (Raspberry Pi): The Raspberry Pi serves as the central processing unit for executing image processing and artificial intelligence algorithms that operate on data from the ship. It interfaces with the Raspberry Pico/Arduino Leonardo via serial communication protocol for data transfer and camera data processing. Its functions include the processing of sensor data, motor control, navigation, and cleaning routines for the ship. The card is sized appropriately for the ship's connection box.

MICROCONTROLLER (Raspberry Pico/Arduino Leonardo): The microcontroller, either the Raspberry Pico or the Arduino Leonardo, serves as a vital component for linking the LoRa module and motor control units. It is deployed as a communication module for this purpose.

LoRa: E22 900T22D LoRa module is used for failure, safety and accident prevention in case the ship's wifi connection is lost. This module can provide up to 7 km connection in the external environment.

6.5.2.3. Locomotion Modules:

MOTOR: The motor, which is isolated with a saltwater-resistant bearing and creates a thrust force suitable for the Vatoz, has high efficiency and is resistant to impacts. The motor, which we bought with ESC, will directly provide data to the motors with the control card. Thrusters with propellers will be used depending on the thrust force needed for the ship to perform its tasks. These motors operate on 12-24 V and have 6.8 kg thrust force at 50% power.

RASPBERRY PI CAMERA AND LENS: The Raspberry Pi HQ Camera has been chosen to acquire images that will be analyzed by the image processing algorithms of the ship, to identify marine waste present on the water surface. The camera is equipped with a wide-angle lens featuring a 6 mm focusing distance, which meets the specific requirements of our project. The camera is used to capture both images and videos of the water surface and is considered a critical component for monitoring the water quality and detecting marine debris.

BATTERY: This component has been integrated to fulfill the power requirements of the vessel. To achieve this, a set of 6 li-ion batteries with a capacity of 22.2 V and 3.2 Ah, capable of delivering 2C, have been employed. These batteries are designed to be waterproof and high-capacity, providing sufficient power to operate the ship for an extended period.

VOLTAGE SENSOR: We will integrate a voltage sensor into the Arduino Leonardo/Raspberry Pico microcontroller to enable real-time monitoring of the battery's voltage. This sensor utilized to read the battery's voltage and current values, which is crucial for mitigating damage and preventing malfunctions caused by voltage fluctuations.

6.5.2.4. Localization Modules:

GPS: The GPS module is utilized to ascertain the current location and coordinates of the ship, as well as to determine its position and orientation on the map. Additionally, it employed to compute speed information based on its location on the map. The GPS module plays a crucial role in controlling navigation and the movement of the ship.

ACCELERATION, SLOPE AND COMPASS SENSOR: In the project, the MPU6050 6 Axis Acceleration and Gyro Sensor will use the HMC5883L/QMC5883 card for the compass, and the acceleration and tilt data of the boat will be taken in the X, Y, Z axes. It is used to measure the Earth's magnetic field. Essential for providing accurate compass readings, which is important for navigation.

6.5.2.5. Enviromental Sensors:

TEMPERATURE SENSOR: The temperature sensor card is a sensor with a PCB prepared for easy connection. It will be used to measure and display the instant temperature values of the ship's sub-electronic components, batteries, and sea temperature values on the interface.

HUMİDİTY SENSORS: Humidity sensors used to monitor the moisture levels inside the ship's hull. Excessive moisture inside the hull can lead to the growth of mold and mildew, which can be damaging to both the ship and its crew. By monitoring the humidity levels inside the hull with a sensor, preventative measures can be taken to prevent the growth of mold and mildew.

All hardware components are connected to Raspberry Pi. This includes GPS module, temperature sensor, magnetometer, Lidar sensor, motor, camera and battery. Raspberry Pi, GPS module, temperature sensor and magnetometer are mounted on the upper structure of the boat. These sensors were preferred in the superstructure to enable them to see the signal flow clearly. The lidar sensor is attached to the front of the boat's superstructure. This sensor is mounted at a height that allows it to detect obstacles and accurately measure distances. The engine is located at the lower back of the waterline of the hull of the boat. It must be connected to the propeller that provides the movement of the boat.

6.5.2.6. PCB Design:

Initially, an examination of the electrical system requirements for the autonomous ship was conducted to identify the appropriate components such as microcontrollers, sensors, and communication modules needed for the design. The next step involved creating a schematic design that depicted the connections between the various components using the EAGLE PCB design software.
Subsequently, the panel layout design process commenced, which entailed placing the components on the board and routing traces to establish connections between them. Prior to manufacturing the PCB, a thorough review of the design was carried out to ensure that it complied with the requirements and that there were no errors or issues with the layout. After obtaining approval for the design, Gerber files were generated from the design software to facilitate the fabrication of the PCB. Upon completion of the PCB manufacture process, the components were soldered onto the board and the board was mounted. Lastly, a comprehensive testing was carried out to ensure the functionality of the PCB and to ascertain that all components functioned as expected.

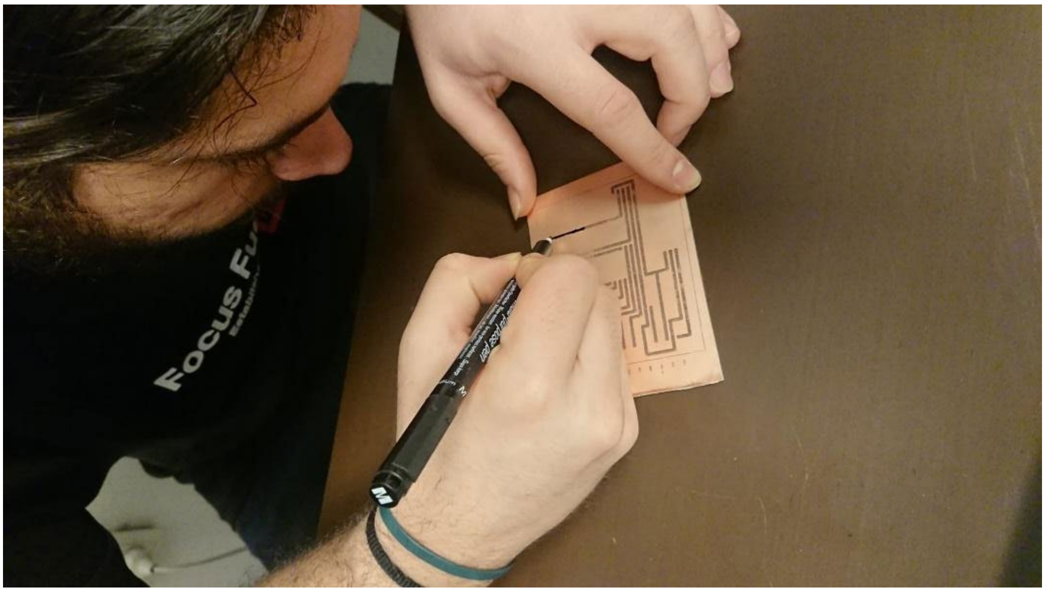


Figure 30. PCB Design Process

The manufacturing of printed circuit boards (PCBs) involves a widely-used technique called PCB etching. The purpose of this process is to selectively eliminate the unwanted copper from the board while preserving the desired traces and pads. To initiate this process, the copper pattern is first transferred onto the board through toner transfer, where the circuit design is printed onto toner transfer paper, which is then placed onto the copper-clad board and heated with a hot iron or a laminator, allowing the toner to melt and transfer the image (Figure 30) onto the copper surface. Following this, the board is immersed into a PCB etching solution, usually ferric chloride, which removes the unwanted copper. The etchant is stirred to ensure even etching and to remove copper particles from the board's surface. The etching time is dependent on the thickness of the copper layer and the concentration of the etchant solution. After the etching is complete, the board is removed from the etchant and washed thoroughly with water to remove any remaining etchant and other residues. A solvent is then used to remove the toner from the board, resulting in the desired copper traces and pads. Finally,(Figure 31) holes are drilled for the components, and a solder mask and a silkscreen are applied to identify the components and traces on the board, resulting in a fully functional PCB that can be utilized in various electronic devices.

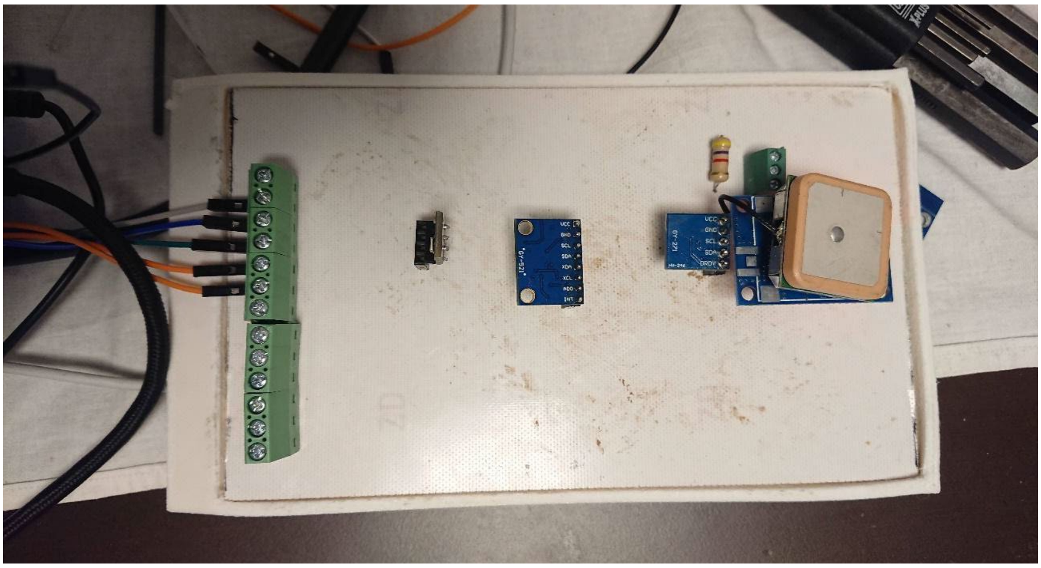


Figure 31. Inıtial PCB Board

6.5.3. Development of Control System Software

The module responsible for controlling the motion of the ship is composed of two propellers, each of which is independently operated by its own motor. The module employs differential propulsion technology, which enables the propellers to alter their direction. The gyroscope provides steering signals for the ship, and numerical analyses of hull and fluid dynamics are conducted during the prototype stage to assist with engine startup and steering. Two control methods are employed to regulate the ship's movement: manual control, which is implemented via a remote control device, and autonomous control, which utilizes trajectory planning algorithms in conjunction with appropriate control techniques. Initially, the system was tested using manual control.

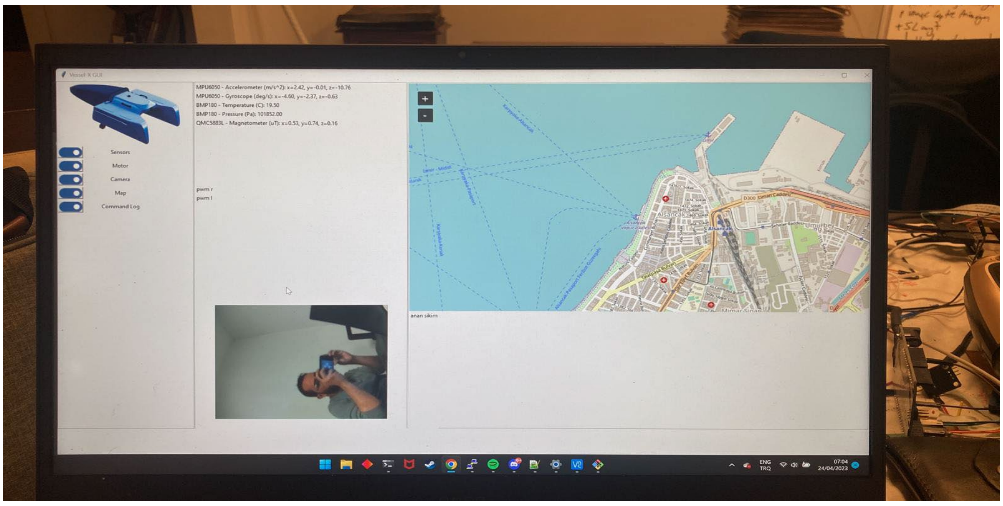


Figure 32. Initial Control System Software UI

Manual Control:

For the manual control system, the receiver of the remote control was installed on the Arduino Leonardo. Then, the received PWM (Wave Width Modulation) signals were transferred to Raspberry Pi 4 from the usb output. The received signals are transmitted to the electronic speed controller (ESC) successfully. While the first three channels in the control provide the control of the IDA (Unmanned Marine Vehicle); In the fifth channel, the motors were adjusted to control the on-off. These have been checked. The controls were made on the land whether the product made simple maneuvers, whether the signals were sent to the motors and whether the on-off button was working, and the results were positive.

Autonomous Control:

After examining the documentation of the sensors used for autonomous control, a python code was written to process the data. The connections of the sensors over i2c were controlled by commands. Received data has been brought to an order that the user can access and understand. The initial desifn of the user graphical interface you see in (Figure 32) has been coded. Then this graphical user interface (GUI) was checked to see if the data came in regularly. As a result of the tests, it was decided that the health of the data was good. A window has been added to the UI where users can add waypoints and plot the possible task path, along with the data that follows. An array was created to process this data. With the latitude and longitude data in this series, it was aimed to reach waypoints autonomously.

Autonomous navigation will use data from GPS and user-defined waypoints. The GPS data is compared with the available waypoint coordinates and the target heading and distance are calculated. Autonomous navigation will be performed according to the pre-loaded route, position and orientation values measured by the built-in GPS module and magnetometer. It will be able to make changes to the pre-loaded route due to the presence of a possible obstacle through the cameras.

Throughout the navigation algorithm workflow, it is essential to ensure that the system operates safely and reliably. This requires rigorous testing and validation of software and hardware components. Additionally, it is important to comply with relevant regulations and guidelines for autonomous ships, including those related to safety, security and privacy.

6.5.3.1. Navigation System

Autonomous navigation in ship relies on the collection of data from GPS and LIDAR sensors, as well as the use of user-defined waypoints. The GPS data is used to calculate the target heading and distance by comparing it to the available waypoint coordinates. Furthermore, autonomous navigation is performed by taking into account the pre-loaded route and the position and orientation values measured by the built-in GPS module and magnetometer. In case of any obstacle, LIDAR can adjust the preloaded route. To ensure the safety and reliability of the navigation algorithm, it is crucial to conduct thorough testing and validation of both hardware and software components. Moreover, complying with relevant regulations and guidelines concerning safety, security, and privacy of autonomous ships is imperative.

1.Sensor data collection and processing: In accordance with the hardware development work package, a board was designed with the primary objective of data aggregation from diverse sensors. To achieve this, a circuit board was meticulously devised to facilitate the comprehensive collection of sensor data. The utilization of i2c and serial ports was paramount in ensuring the proper and controlled acquisition of data. This meticulous approach was necessary to ensure the consistent and regular retrieval and transmission of data. Considerable attention was given to ensuring the uniqueness of sensor addresses, as the presence of identical addresses could potentially result in data conflicts. To preemptively address this issue, the deployment of a secondary i2c router was implemented whenever conflicting addresses were encountered. This strategic measure effectively mitigated any potential problems arising from address conflicts. The collected data is subsequently transmitted via wifi, utilizing established communication protocols for seamless transfer to the interface responsible for system control. This meticulous arrangement guarantees the accurate and expeditious delivery of data to the designated locations for thorough analysis and processing. Moreover, meticulous connections were established on the Raspberry Pi, thereby ensuring the smooth operation of the entire system and the efficient collection and transmission of data. Acting as the central control unit in this process, the Raspberry Pi orchestrates the appropriate processing and routing of the collected data, thus ensuring its accuracy and integrity.

2. Localization: Localization, generally referred to as determining the precise position of a vessel relative to its surroundings, constitutes a crucial process within navigation algorithms. Primarily, GPS data is commonly utilized to ascertain the general location of a vessel, enabling us to determine its geographical coordinates. However, due to the inherent limitations in GPS data accuracy, other sensors are also employed. Magnetometer and gyroscope sensors come into play in this context. The magnetometer measures the Earth's magnetic field, thereby determining the vessel's heading, while the gyroscope tracks the vessel's changes in direction and rotations, providing directional information. By integrating these data with GPS measurements, a more accurate estimation of the vessel's exact position and heading can be achieved.

Another significant aspect in the localization process is the Probability Estimation System, which takes uncertainties and errors into account. Sensor data may not always be entirely accurate and may contain uncertainties. The Probability Estimation System aids in minimizing these uncertainties and errors by incorporating them into our predictions. In these predictions, a form of filtering is applied by combining the mathematical model of the vessel's motion with the data from the gyroscope sensor.

This filtering assists in enhancing the accuracy and reliability of position and heading estimations. As a result, a more precise control over the real-time position and heading of the vessel is attained.

3. Path planning: Path planning is a critical component of an autonomous vessel's navigation system, involving the determination of the optimal route to reach the destination while avoiding obstacles and other hazards. Once the vessel's position and environment are established, the navigation algorithm focuses on planning the path to the intended destination. Path planning algorithms consider obstacles, water depths, and other relevant factors to determine the most suitable path towards the destination and continuously update themselves.After the environment map is constructed, the vessel's destination is selected, which incorporates inputs from an automated system that either selects the destination based on predefined criteria or receives inputs from the vessel operator. The subsequent step after route generation is to ensure that the vessel follows the route without colliding with any obstacles or hazards. This involves the use of algorithms that detect obstacles along the vessel's path and generate alternative routes using cameras to avoid them.
Subsequently, the route is optimized to minimize travel time, fuel consumption, or other criteria. This involves the use of algorithms that adjust the vessel's speed and direction to optimize the route according to predefined criteria. The vessel's sensors and control systems monitor the vessel's progress and make necessary adjustments to ensure that it follows the planned route and reaches the destination safely.

4. Control: The final step in the workflow of the navigation algorithm involves controlling the vessel's DC motors, including thrusters and rudder, to follow the planned route. This control system ensures that the vessel adjusts its speed and direction to adhere to the planned route and navigate around obstacles. This process entails the adjustment of other control surfaces, such as the vessel's rudder and electronic speed control board. The software control system developed for this purpose continuously monitors the vessel's sensor data and utilizes feedback control algorithms to adjust the vessel's movements based on the disparity between the desired and actual states. This enables the vessel to navigate safely and accurately.
Collision avoidance algorithms detect obstacles along the vessel's path and generate

alternative control inputs to prevent collisions. These algorithms plan to utilize information obtained from the vessel's sensors or external sources such as AIS data and weather forecasts. In the event of an emergency, the control system activates emergency procedures, which may involve actions like stopping the vessel's motors or sending distress signals.

6.5.3.2. *Control System UI Design*

The goal of the system is to serve as a real-time support system for ensuring the safe navigation of an unmanned ship. To achieve this, an interface design was created using "Figma" and the QT program was developed using Python. The interface (Figure 33) includes various commands such as heading, pitch yaw, wireless connection status, battery, camera, waste capture commands, local weather, rudder control, navigation, and speed control . The purpose of transmitting data from Raspberry Pi is to provide telemetry data, and to enable instantaneous monitoring, task assignment, and autonomous ship control through a single interface. The system aims to notify the user of alarming conditions such as water leakage, heating or damage to electronic components, low batteries, and environmental warnings, while also managing the communication network.

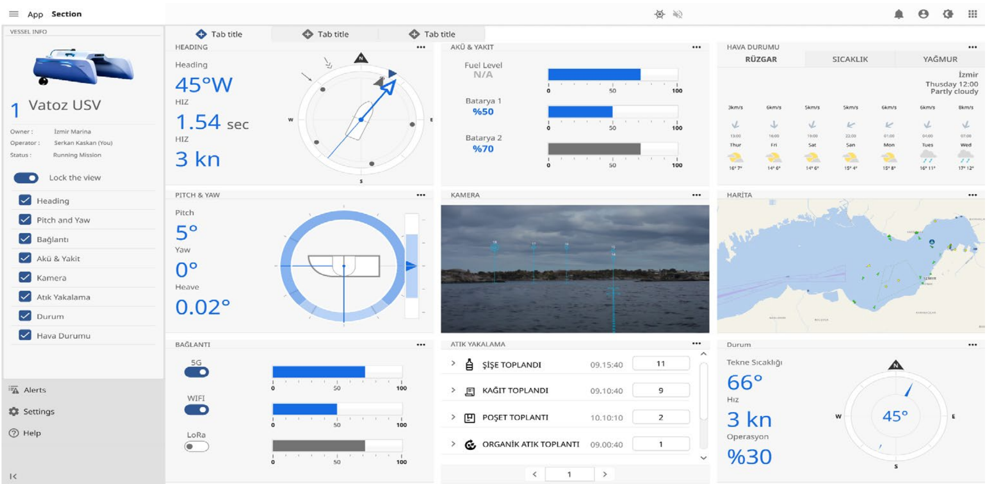
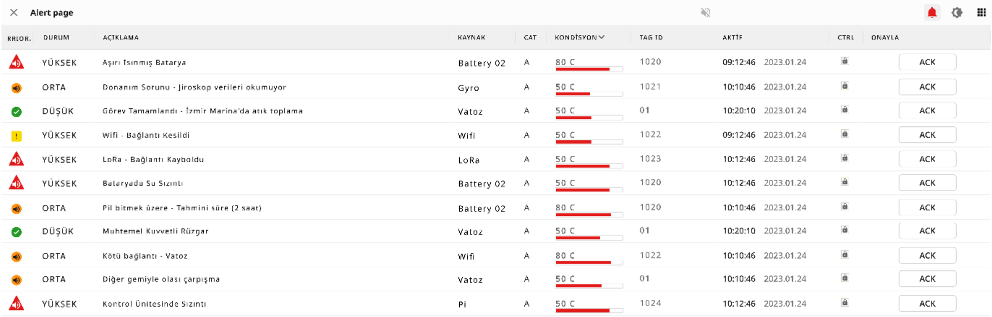


Figure 33. Autonomous Ship Control Interface


Alert page

RRIOR.	DURUM	AÇIKLAMA	KAYNAK	CAT	KONDİSYON	TAG ID	AKTİF	CTRL	ONAYLA
	YÜKSEK	Aşırı Isınmış Batarya	Battery 02	A	80 C	1020	09:12:46 2023.01.24		ACK
	ORTA	Donanım Sorunu - Jiroskop verileri okumuyor	Gyro	A	50 C	1021	10:10:46 2023.01.24		ACK
	DÜŞÜK	Görev Tamamlandı - İzmir Marina'da atık toplama	Vatoz	A	50 C	01	10:20:10 2023.01.24		ACK
	YÜKSEK	Wifi - Bağlantı Kesildi	Wifi	A	50 C	1022	09:12:46 2023.01.24		ACK
	YÜKSEK	LoRa - Bağlantı Kayboldu	LoRa	A	50 C	1023	10:12:46 2023.01.24		ACK
	YÜKSEK	Bataryada Su Sızıntı	Battery 02	A	50 C	1020	10:12:46 2023.01.24		ACK
	ORTA	Pil bitmek üzere - Tahmini süre (2 saat)	Battery 02	A	80 C	1020	10:10:46 2023.01.24		ACK
	DÜŞÜK	Muhtemel Kuvvetli Rüzgar	Vatoz	A	50 C	01	10:20:10 2023.01.24		ACK
	ORTA	Kötü bağlantı - Vatoz	Wifi	A	80 C	1022	10:10:46 2023.01.24		ACK
	ORTA	Diğer gemiyle olası çarpışma	Vatoz	A	50 C	01	10:10:46 2023.01.24		ACK
	YÜKSEK	Kontrol Ünitesinde Sızıntı	Pi	A	50 C	1024	10:12:46 2023.01.24		ACK

Figure 34. Warning Status of Navigation Control System

In our designed warning system (Figure 34), we have incorporated a designated field that facilitates the simultaneous visibility of status information by all sensors, enabling prompt monitoring. This field encompasses the temperature values of the sensors, the status information, and the warning region of the time.

6.5.3.3. Algorithm Development

This part discusses various algorithms used in autonomous ships for obstacle detection, collision avoidance, pathfinding, and image processing. LIDAR is used to detect obstacles, and sensor fusion is used to combine data from multiple sensors for more accurate detection. Obstacle detection involves identifying the position, size, and speed of obstacles using supervised and unsupervised algorithms. Collision avoidance algorithms, such as the Potential Field Method or the Velocity Obstacle Method, are used to calculate the optimal trajectory for the ship to avoid the obstacle. Pathfinding algorithms, such as A* or D*, are used for path replanning and execution. Image processing algorithms involve image capture, pre-processing, object detection and recognition, image segmentation, data labeling, and training. The detection algorithm has been integrated with an autonomous watercraft and tested in field tests. Overall, these algorithms enable autonomous ships to navigate safely and avoid obstacles while accomplishing their tasks.

6.5.3.3.1. Obstacle avoidance and Path Planning Algorithm

Upon detecting an obstacle, information regarding its position, size, and velocity is collected to calculate the potential collision risk and adjust the vessel's trajectory to avoid the obstacle. In the current system, successful obstacle detection rates have been achieved using only cameras. Additionally, Kalman Filtering has been applied to objects identified as vessels to estimate their intended directions, enabling the detection of moving obstacles. To calculate the optimal trajectory for the vessel to avoid obstacles, collision avoidance algorithms such as the Potential Field Method or Velocity Obstacle Method have been employed. These algorithms take into account the vessel's constraints, such as maximum speed and turning radius, as well as the position and size of the obstacle. Based on the vessel's current position and velocity, predictions are made, and collision prediction algorithms consider the vessel's speed, direction, and constraints to determine the likelihood of a collision.

Update Path: When the ship successfully avoids an obstacle, the path is updated to proceed towards the intended destination. The ship's position is determined using diverse sensors such as GPS, IMU, or visual odometry. By continuously monitoring the ship's position, deviations from the planned path can be detected and corrected accordingly.

6.5.3.3.2. Pathfinding Algorithms

Navigation and control via Python software language is defined by understanding the logic of the algorithm and drawing the flow chart of the algorithm on paper. After choosing the Python programming language for the implementation of the algorithm, it was written on the specified programming language during the trial phase of the algorithm and the operation of the algorithm was observed as a prototype.

1. Path Deviation Detection:
   Following the update of the ship's position, it becomes crucial for the system to identify any deviations from the predetermined path. These deviations can occur due to various factors, such as alterations in water currents or unexpected obstacles.
2. Road Replanning:
   If the ship is found to have deviated from the intended path, the subsequent step involves recalculating the path. Path replanning encompasses determining an alternative route that circumvents obstacles and directs the ship towards the desired

destination. Various algorithms, such as A* or D*, can be employed to generate the new path.

3. Path Execution:
   The final stage entails executing the newly computed path. The ship's control system adjusts the ship's course and speed to follow the revised route. Constant monitoring of the ship's position is performed, enabling route updates whenever necessary.

6.5.3.3.3. Image processing Algorithms

By defining the camera (Figure 35) on the Raspberry Pi, the objects were defined on Python. In this process, attempts were made to define the images displayed on the Raspberry HQ camera and to classify the defined images for the future.

1. Image processing: Once the images are captured, they undergo pre-processing to enhance their quality and prepare them for subsequent operations. Hyperparameters relevant to object recognition are considered during this process.

2. Object detection and recognition: The YOLO (You Only Look Once) image processing algorithm is employed for object detection. After training the hyperparameters for 300 epochs and 30 generations, parameters yielding a high confidence rate for four label formats were identified. Subsequently, object detection training, encompassing 1200 epochs, was initiated. Hyperparameters for image segmentation, which involve partitioning an image into regions or segments based on features such as color, texture, and density, were utilized. This is commonly employed to distinguish objects from their backgrounds or identify regions of interest within an image. The hyperparameter training facilitated easier detection and differentiation of waste materials, due to its ability to provide a higher level of reliability.

3. Data labeling and training: To develop a waste detection algorithm, the image dataset was labeled with accurate object classes such as plastic bags, bottles, and organic waste. Subsequently, the majority of the generated dataset was allocated for training, while the remaining 20% was reserved for validation and testing purposes.

4. Implementation and testing: Following the development and training of the image processing algorithms, they were implemented in the software and thoroughly tested to ensure they meet performance criteria and operate reliably in various scenarios. The object recognition algorithm was integrated with an autonomous marine vehicle capable of identifying and collecting marine debris, and its reliability was tested through field trials.

Figure 35. Image identification experiments

6.5.4. Production Development of Vatoz

The production of a marine cleaner such as the "Vatoz" requires a meticulous manufacturing process that ensures durability, longevity, and efficiency. One of the key considerations during production is the need to minimize frictional forces to optimize the vessel's movement on water. To achieve this, the hull of the vessel is preferably made of fiberglass, known for its robustness and durability.

The hull construction process involves laser-cutting the keel line (posts) and joining them together. The keel line, which is cut using the laser-cutting method, is assembled by joining the individual pieces together. Subsequently, a thin cardboard coating is applied (Figure 36) to create a smoother surface for the fiberglass material that will be used on the vessel.

Figure 36. Cardboard coating process for Vatoz

The construction of the hull is achieved using a fiberglass mold (Figure 36). The mold, made of 4mm fiberglass and resin, is used to shape the fiberglass material that will be used on the vessel after the covering process. The shaping process also involves using 4mm fiberglass and resin. Excess resin is removed using rollers, and the material is cured to complete the process.

After the shaping process is complete, holes are drilled for the hatchways, cameras, handles, and motor placements (Figure 37). Subsequently, any bumps, flaws, and openings are filled with putty, and the vessel is sanded to eliminate them. At this stage, the application of putty to fill gaps and create a smooth surface is critical in ensuring efficient movement of the vessel on water. Once the holes are drilled, the bumps, flaws, and openings are covered with putty, and the vessel is painted.

Figure 37. Glass fiber and Putty coating process

To complete the vessel's external coating, three coats of gelcoat are applied using a spray gun or paintbrush. As gelcoat is a toxic material, protective masks and glasses are used during application, and a sterile environment is maintained. Additionally, the keel is covered with anti-fouling paint to enhance durability (Figure 38), while the rest of the vessel is painted with white spray paint. Finally, a high-quality, water-resistant and weather-resistant paint is applied to ensure the vessel's longevity and durability.

Figure 38. Paintwork of Vatoz

Subsequently, the covers are mounted (Figure 39), and the electronic circuits are connected, followed by the application of silicone to ensure water-tightness. These steps complete the production process of the vessel, making it ready for use.

Figure 39. Hardware Assembly process

After the production of the mold model was completed, the assembly of the electronic components began. The placement of these components was determined based on calculations from the static and hydrodynamic simulations of the Vatoz. In particular, the batteries, which are one of the equipment with high volume and weight, were placed according to these calculations. The controllers and sensors were placed in the SuperStructure. Cable channels were opened and motor connections were made.

6.5.5. *Test and Trials*

6.5.5.1. *System's Holisctic Hardware Tests*

This work package includes testing of the electronic components installed on the ship. Before launching the ship, tests of the equipment were conducted on land (Figure 40). After each electronic component passes their tests, the subsystems are tested to ensure they work together correctly. This includes testing the engine system, cleaning mechanism, communication modules and sensor and camera systems. After component level testing was done, subsystem level testing was done to ensure all components work together as a system. The following subsystem level tests have been performed:

Figure 40. System's holistic Tests

6.5.5.1.1. Electrical System:

The electrical system has been tested to ensure that all electrical components work together and that the ship's battery can power the entire system. Each component of the electrical system has been individually tested to ensure its functionality and performance, Tests have been made to verify the Battery, capacity and discharge rate, the motor controller has been verified by controlling the speed and direction of the DC motor. The sensors were tested to verify their accuracy and reliability, and the communication module was tested to check its ability to transmit data wirelessly.

6.5.5.1.2. Mechanical System:

The mechanical system, including the DC motor and the cleaning mechanism, has been tested to ensure that the Stingray can move and clean on the water surface. This system has been evaluated as the design and production of the network system we have designed to collect the garbage and the input probe that will be integrated into the Stinger.

6.5.5.1.3. Sensor and Camera System:

The sensor and camera system has been tested to ensure that the ship can accurately detect marine debris.

1) MPU6050: The MPU6050 6-Axis Acceleration and Gyro Sensor is a six-axis motion sensor that measures the ship's direction and acceleration. This sensor, which helps the ship to maintain its balance and stability, has been integrated into the Stingray we have designed and holistic hardware tests have been carried out. The MPU6050 sensor is connected to the Raspberry Pi via the I2C bus. I2C bus, multiple devices communicate with Raspberry Pi using two cables, one (SCL) and the other (SDA).

2) Lidar: The LIDAR (light detection and range) sensor used in this project is a 2D scanning sensor that emits a laser beam and measures the time it takes for the laser to return from objects in the field of view. The sensor is mounted on the stingray's superstructure and rotates continuously, providing a 360-degree view of the environment. The sensor is used to calculate the distance to the object in front of the ship. Usage tests were conducted for Point cloud data, obstacle detection and avoidance, as well as localization and mapping, generating a point cloud of the surrounding environment that can be used to create a 2D map of the ship's surroundings. On this ship, the LIDAR sensor is used in conjunction with other sensors and cameras to provide a comprehensive view of the environment. The sensor data is processed by the onboard computer system (Raspberry Pi) to create a map of the ship's surroundings and to control the ship's movement and cleaning operations.

3) GPS: GPS supports various satellite navigation systems, including Glonass and Galileo, and can simultaneously track 22 satellites. The GPS sensor communicates with the control computer using position data to determine the ship's position, speed

and heading direction. This information is used for the ship's autonomous navigation and route planning. The accuracy of the GPS sensor can be affected by several factors, including the number and quality of satellite signals received, atmospheric conditions, and signal interference. Therefore, to increase the accuracy of the GPS sensor, it is positioned on the superstructure with an external GPS antenna mounted on the ship and providing a clear view of the sky. During testing, the accuracy and reliability of the GPS sensor were evaluated by subjecting the GPS sensor to various scenarios, including open water testing and testing in different weather conditions. The results of the test showed that the UBLOX GYGPSV1 Neo-8M GPS module provides accurate and reliable location data, enabling the ship to navigate autonomously and effectively complete the cleaning mission.

4) HMC5883L/QMC5883: Used via a Python interface to access the I2C bus on Raspberry Pi. The HMC5883L/QMC5883 sensor has been used with other sensors such as the MPU6050 to convey the ship's direction and movement. This information can be used to control the movement of the ship and ensure that it is operating correctly.

5) DS18B20: DS18B20 is a digital temperature sensor used to measure water temperature on ship. As a waterproof and compact sensor that can be easily mounted on the ship, the DS18B20 sensor uses a one-wire communication protocol that allows multiple sensors to be connected to a single data line. The sensor provides a 12-bit resolution temperature measurement with an accuracy of ±0.5°C over the temperature range of -55°C to +125°C. The sensor also has a unique 64-bit serial code that allows multiple sensors to be connected to the same data line without interference.

6.5.6. Trial Results

Autonomous Control System: The autonomous control system has been tested to ensure that the ship can navigate autonomously, avoid obstacles and pick up debris.

Communication System: The communication system between the ship (Figure 41) and the remote-control unit has been tested to ensure that it works reliably and that the operator can control the ship remotely. The autonomous water surface cleaning vessel is a critical part of the Vatoz project, as the communication system allows data to be transmitted between the vessel and the shore-based control system. The communication system includes various components, including Lora, Wi-Fi and cellular network connectivity.

The Lora module is used for long range wireless communication between the ship and the shore-based control system. It operates at a frequency of 868 MHz, allowing reliable communication over long distances. The LoRa module is connected to the Arduino Leonardo, which is responsible for transmitting and receiving data. The transferred data includes information about the vessel's position, orientation, speed, battery level and cleaning operating status.

Figure 41. Vatoz

In addition to the LoRa module, the ship is also equipped with Wi-Fi. These communication methods allow remote access to the ship's data from anywhere in the world. The Wi-Fi module connects to the Raspberry Pi acting as the host. Tests were conducted at both the component and subsystem levels to ensure the reliability and security of the communication system. The component level test includes verification of the correct operation of the Lora module, the connection of the Wi-Fi module. This test involved sending and receiving data between the ship and the shore-based control system under various conditions, including different distances and environmental factors. With these tests, various scenarios such as signal loss or network outage are simulated to ensure that the communication system can continue to run and operate the data.

The Vatoz (Figure 40) has undergone environmental testing to ensure it can function in a variety of conditions, such as different weather conditions and water types. The ship's performance is also tested in real-life conditions such as waves, wind and water currents. Durability tests have been conducted to test the continuous long-term operation of the electronic hardware system to determine its durability and reliability. This test ensures that the ship can operate for a long time without maintenance. Testing of the ship's collision avoidance system, emergency stop procedures and stability in different water conditions were also carried out.

CHAPTER 7: CONCLUSION

7.1.Evaluation of the Project and Methodology

The production process of Vatoz was initially formulated based on a comprehensive business package plan. It comprised a total of four distinct work packages, namely the Establishment of Design Criteria and Requirements, Development of Hardware and Software Systems, Development of Control System Software, and Trial Results. This planning phase was assessed in accordance with the double diamond model, and research and development procedures were devised accordingly. Throughout the process, some deviations emerged within the smaller work packages, which adhered faithfully to the planned model.

7.1.1. Competencies Acquired Throughout the Project Duration

This process has provided insights into the disparities between planned and actual research and development activities. Throughout the course of the autonomous water surface cleaning vehicle project, team members have acquired a diverse range of technical competencies. These competencies encompass the following:

The team has developed proficiency in the design and assembly of printed circuit boards (PCBs) for the electrical system of the autonomous water surface cleaning vessel. This expertise has been acquired through practical experience in creating schematics, layout designs, and manufacturing PCBs using diverse software tools and techniques. The team members are knowledgeable in hardware design concepts, encompassing PCB layout, component selection, and circuit design. They have also gained competence in embedded systems and microcontroller programming, having worked with Arduino and Raspberry Pi to interface with various sensors and actuators. Through testing the written code in the physical environment, the team has further honed their skills in controlling the mechanical and electrical systems of the vessel.

Proficiency in multiple microcontroller programming languages, such as C, Python, and C++, has enabled the team to develop interaction systems with universal devices.

Furthermore, the team has acquired expertise in working with a range of sensors and camera systems, including, GPS, MPU6050, HMC5883L/QMC5883, DS18B20, LoRa, and Raspberry Pi HQ Camera. Integration of these sensors and cameras into the vessel's control system for navigation, obstacle avoidance, and data collection has been successfully accomplished. The team members have also gained knowledge in mechanical and naval engineering principles and techniques, such as 3D modeling, rapid prototyping, and fabrication. They have designed and constructed the mechanical system of the vessel, including the hull, propulsion system, and cleaning mechanism. Practical experience in on-site boat manufacturing techniques has been acquired.

The team has demonstrated expertise in developing communication systems for the vessel, incorporating LoRa for long-distance communication between the vessel and the ground station. Additionally, a web-based user interface has been developed to monitor the vessel's status and control its operations. Implementation of communication protocols like SPI, I2C, and UART has been successfully executed. Proficiency in various wireless communication protocols, including LoRa, Wi-Fi, and Bluetooth, has been gained to enable communication between different components of the autonomous vessel, such as sensors, cameras, and engines. The team has acquired skills in data transmission and reception, encompassing the management of data packets, optimization of data transfer rates, and handling of data loss and errors.

Testing and validation of the vessel's performance and functionality have been a focus, and the team has gained experience in this area. They have developed comprehensive test plans, conducted component and subsystem level tests, and performed field tests to validate the autonomous capabilities of the vessel. Troubleshooting skills have been developed, enabling the team to identify, isolate, and resolve issues in software and hardware systems. Unit testing has been performed to ensure the proper functioning of each software component and to identify any potential errors resulting from code modifications. Integration testing has been conducted to address interface problems between different components, and extensive testing has been carried out to verify the overall system's intended operation.

In summary, the team has acquired a wide range of technical competencies necessary for the development of autonomous systems, including expertise in electronic design, software development, mechanical engineering, and testing and verification. These skills will prove invaluable for future projects in the field of robotics and autonomous systems.

7.1.2. Evaluation of the Double Diamond Model Throughout the Project Duration

The Double Diamond model is a design thinking framework that consists of four phases: Discover, Define, Develop, and Deliver.;

Discover:

During the Discover phase of the Autonomous Water Surface Cleaning Vessel, Vatoz project, the team engaged in research and exploration to gain a deep understanding of the problem of marine pollution and identify potential solutions. The team conducted literature reviews, environmental studies, and engage with stakeholders to gather insights and data. Situations experienced in this phase include:

1)Researching and identifying the extent and impact of marine pollution.
2)Discovering the different types of marine debris and their sources.
3)Exploring existing technologies and approaches for water surface cleaning.
4)Conducting interviews or surveys with experts, environmental organizations, and potential end-users to understand their perspectives and needs.

Define:

In the Define phase, the team narrowed down the problem space and defines the specific goals, requirements, and constraints of the project. This phase involved synthesizing the research findings from the Discover phase to establish a clear direction. Situations experienced in this phase include:

1)Defining the problem statement, such as designing an autonomous water surface cleaning vessel to remove marine waste efficiently.
2)Identifying key user needs and defining the desired outcomes of the project.
3)Establishing design criteria and specifications for the vessel.
4)Conducting market analysis to identify potential target markets and competitors.

Develop:

The Develop phase involved generating ideas, prototyping, and refining solutions based on the defined requirements. This phase was focused on creating tangible outputs and testing them to gather feedback and iterate.

1)Generating multiple design concepts for the vessel's hardware, software, and control systems.
2)Building prototypes and conducting tests to evaluate their functionality and performance.
3)Iterating and refining the vessel's design based on user feedback and technical feasibility.
4)Developing and integrating the necessary sensors, cameras, and communication systems.

Deliver:

In the Deliver phase, the focus was on implementing the final design, preparing for production, and launching the autonomous water surface cleaning vessel. This phase involved finalizing the design, manufacturing the vessel, and ensuring it meets the required standards and regulations. Situations experienced in this phase may include:

1)Finalizing the vessel's design, including the hull structure, propulsion system, cleaning mechanism, and control systems.
2)Conducting extensive testing and validation to ensure the vessel's performance and reliability.
3)Establishing manufacturing processes and sourcing materials.
4) Planning to prepare marketing and communication strategies for the launch of the vessel.

7.2. Bluetech and Teknofest Competition Process

7.2.1. Teknofest (Teknofest Aerospace and Technology Festival) Competition

The present study demonstrates the successful implementation of the Autonomous Water Surface Cleaning Vessel project, which participated in the Teknofest competition and achieved first place in the "Environmental Energy Technologies" category with the product named Vatoz in İstanbul Atatürk Airport. Teknofest, the Aviation, Space, and Technology Festival, is a prominent event in Turkey that focuses on aviation, technology, and space technology. Organized by the Turkish Technology Team Foundation and the Ministry of Industry and Technology, it serves as the country's premier and exclusive festival aimed at fostering the development of national technologies and raising public awareness in this field.

Figure 42. Vessel X Team, Left to Right, Umut Kanpalta, Oğul Görgülü, Serkan Kaska, Orhan Eryiğit

As leader of the Vessel X team, we competed in the "University and Above Category", and with a team of five members (Figure 42), Oğul Görgülü (Interior Architect and Yacht Designer), Umut Kanpalta (Computer Engineer), Rıza Serkan Kaskan (Al, Algorithm Engineer), Orhan Eryiğit (Software Engineer), Barış Genco Atalay (Naval Architect) involved in the project, we emerged as the first-place winner among 83 finalist teams in the Teknofest area in Istanbul. The project received a total of over 19,949 applications, indicating its significant impact and recognition within the competition. More than 332,000 teams competed in this competition in 41 main competitions and 102 different categories in 2023.

The process commenced with meticulous referee evaluations carried out by domain experts. Starting with the preliminary evaluation report on November 6, 2022, the project underwent thorough scrutiny of detailed reports and suitability assessments, eventually achieving the status of a finalist with a score of 91.67. Prior to Teknofest Istanbul, we commenced preparations for the Vatoz project, conducting hardware tests of the product under challenging conditions and showcasing the prototype Autonomous navigation software to the jury members. The high appreciation received from the jury further reinforced the project's merits. Subsequently, the stand provided by Teknofest allowed for the public exhibition of the Vatoz product, where presentations were delivered to CEOs, personnel, and other stakeholders from diverse institutions and organizations. These interactions elucidated the value propositions, useful models, and usage potentials of the Vatoz product, fostering valuable connections within the industry.

Figure 43. Teknofest Award Ceremony

On May 2, 2023, during the award ceremony (Figure 43) at Teknofest Istanbul, we had the honor of receiving the First Prize from Selçuk Bayraktar, the Chairman of the Board of Directors and Technology Leader of Teknofest, who is also a minister of the Republic of Turkey and one of the festival's founding members. This prestigious recognition further solidified our commitment to advancing our R&D activities as we return to Izmir.

The Teknofest competition played a pivotal role in the development and success of the Vatoz project, underscoring its significance within the realm of technological innovation. Participating in the Teknofest competition provided a valuable platform for the Vessel X team to showcase their Autonomous Water Surface Cleaning Vessel, the Vatoz, to a diverse audience of industry professionals, experts, and enthusiasts. This exposure allowed the team to gain recognition and validation for their project, further bolstering its credibility and positioning in the field of environmental energy technologies.
One of the key benefits of participating in the Teknofest competition was the opportunity for rigorous evaluation and feedback from a panel of experts in the field. The thorough and impartial assessment process provided valuable insights and recommendations for further refining and improving the Vatoz project. This feedback, coupled with the team's commitment to continuous learning and enhancement, enabled them to make critical adjustments, fine-tune their approach, and enhance the overall performance and functionality of the Vatoz.

7.2.2. BlueTech İzmir:

As the Vessel X team, we participated in the Bluetech program organized by the Izmir Development Agency, which we applied for on October 12.

BlueTech İzmir Program, which is an entrepreneur promotion program in the field of marine technologies in Turkey, aims to increase synergy in the focus of solutions for the region, the development of blue entrepreneurship and innovation ecosystem in İzmir, and the development of the region's blue entrepreneurship and innovation ecosystem in this field, with the coming of startups and corporate actors operating in this field, organized by İzmir Development Agency. aims to strengthen its position.

Within the scope of the BlueTech İzmir Program, start-ups working in the field of marine technologies, primarily in environmentally friendly maritime technologies, innovative concepts for ships and marine structures, sensors, automation and tracking technologies, advanced manufacturing, security, technologies that generate energy from the sea, shipyards, ports, marinas 6-week training and we entered the intense accelerator process by being taken to the mentoring camp. In this process

We completed the program by being among 9 technology entrepreneurs in the BlueTech İzmir 2022 - Marine Technologies Entrepreneur Acceleration Program. Demo Day (Figure 38), which was held on December 7, was held with the participation of institutions that provide valuable services in the marine sector and environmental protection, and entrepreneurship ecosystem actors.

The BlueTech program (Figure 44) offered a comprehensive range of significant advantages for entrepreneurs operating in the marine technologies sector. Access to funding was a critical component of the program, encompassing financial support mechanisms such as grants, loans, and investment opportunities. Additionally, the program facilitated entrepreneurs' connections with venture capitalists and angel investors, thereby expanding their potential to secure essential capital for their ventures. Mentorship and guidance played a crucial role, with the program pairing entrepreneurs with experienced mentors and industry experts who provide tailored business coaching and guidance. This support system is instrumental in helping entrepreneurs overcome the challenges inherent in their entrepreneurial endeavors and drives the growth of their startups. Networking and collaboration opportunities further augment the entrepreneurial journey by facilitating participation in industry-specific events, conferences, and establishing connections with a diverse network of entrepreneurs, professionals, and institutions. Such collaborations foster knowledge exchange, encourage partnerships, and contribute to the nurturing of innovation while expanding market reach.

Figure 44. BlueTech Demo Day

The BlueTech program offers specialized training through skill development programs, workshops, and access to technical expertise and industry best practices. Entrepreneurs benefit from comprehensive training in emerging technologies and market trends, equipping them with the knowledge and skills necessary to remain at the forefront of a rapidly evolving industry. The program also affords entrepreneurs exposure to potential investors through demo days and investor pitch events, creating platforms for showcasing their innovative solutions.

These events facilitate connections with venture capitalists and business angels, fostering opportunities for funding and strategic partnerships. Furthermore, participants gain enhanced visibility and recognition through program events and media coverage, strengthening their credibility and positioning within the market. By fostering innovation and driving growth in the marine technologies sector, the BlueTech program significantly contributes to economic development, job creation, and further solidifies İzmir's position as a prominent hub for marine technologies.

7.3. Future Goals and Potential Applications of Vatoz

Autonomous Water Surface Cleaning Vessel, also known as the Vatoz, has demonstrated immense potential in addressing the challenges associated with water surface pollution. As we look towards the future, this innovative technology holds significant promise for various applications and can play a crucial role in environmental conservation efforts.

1) Environmental Cleanup and Conservation:
   The Vatoz presents a sustainable solution for water surface cleaning, particularly in lakes, rivers, and coastal areas. Its autonomous capabilities and advanced cleaning mechanisms enable efficient removal of debris, plastics, and other pollutants, thereby contributing to the preservation of aquatic ecosystems. In the future, the Vatoz can be deployed on a larger scale to combat water pollution, protect marine life, and restore the natural balance of water bodies.

2) Water Resource Management:
   Effective management of water resources is essential for ensuring sustainable development. The Vatoz can be utilized to monitor and maintain the quality of water sources. By autonomously detecting and eliminating pollutants, it can help prevent the contamination of drinking water supplies. Additionally, the Vatoz's data collection capabilities can provide valuable insights for policymakers and researchers in understanding water quality trends and implementing appropriate conservation measures.

3) Emergency Response and Disaster Management:
   During environmental emergencies such as oil spills or natural disasters, the Vatoz can be deployed as a vital tool for rapid response and effective mitigation. Its autonomous navigation and cleaning capabilities can aid in the containment and removal of hazardous substances from water surfaces, preventing further damage to the ecosystem. Integrating real-time monitoring and communication systems with the Vatoz can enhance emergency response coordination and facilitate timely decision-making.

4) Research and Monitoring:

The Vatoz can serve as a valuable platform for scientific research and monitoring programs related to water quality and pollution. Equipped with sensors and data collection devices, it can gather comprehensive environmental data, including temperature, pH levels, and pollutant concentrations. Researchers can leverage this data to study the impact of human activities, climate change, and other factors on water ecosystems, leading to informed conservation strategies and policy recommendations.

5) Educational and Awareness Initiatives:

The Vatoz can be utilized as an educational tool to raise awareness about water pollution and environmental sustainability. Its unique design and capabilities make it an engaging and interactive subject for educational programs, inspiring the younger generation to take an active role in protecting the environment. By showcasing the Vatoz in schools, museums, and public exhibitions, communities can be informed about the importance of clean water and motivated to adopt responsible practices.

In summary, the Autonomous Water Surface Cleaning Vessel, Vatoz project's remarkable success at the Teknofest competition in Istanbul, Turkey, has showcased the exceptional capabilities and innovative approach of the Vessel X team. The project emerged as the first-place winner in the highly competitive Environmental Energy Technologies category, outperforming numerous other participating teams. Our participation in the university and above category with the Autonomous Water Surface Cleaning Vessel project was a result of meticulous planning and dedicated efforts. With a team of five highly skilled individuals, we demonstrated our proficiency in developing cutting-edge technologies to address environmental challenges. The project received an overwhelming response, with over 19,949 applications, indicating the significant impact and interest it generated within the competition. As we return to Izmir, our commitment to advancing research and development remains unwavering. This success at Teknofest serves as a catalyst to propel our efforts in contributing to the development of national technologies and driving positive change in environmental sustainability. We are determined to further refine the Autonomous Water Surface Cleaning Vessel project and explore avenues for its practical implementation, thereby promoting cleaner and healthier water surfaces for the benefit of society and the environment at large.

The future applications of the Autonomous Water Surface Cleaning Vessel, Vatoz, is wide-ranging and hold immense potential for environmental conservation, water resource management, emergency response, scientific research, and educational initiatives. By harnessing the capabilities of autonomous technology, the Vatoz can revolutionize the way we approach water surface cleaning, leading to cleaner and healthier aquatic ecosystems for future generations. Continued research, development, and collaboration among academia, industry, and policymakers will be crucial in realizing the full potential of this innovative solution and driving positive environmental change.

It was a very valuable experience to be with the startups working on the marine ecosystem in the Bluetech program and to have the opportunity to have one-on-one meetings with potential customers. New business connections, potential investment negotiations were evaluated. Potential customer feedback has provided invaluable information for the Vatoz project we are working on. In conclusion, the Bluetech program played a pivotal role in nurturing and empowering entrepreneurship in the marine technologies sector. By providing access to funding, mentorship, networking opportunities, specialized training, and exposure to potential investors, the program equips startups with the essential resources and support needed to thrive in the dynamic business landscape. Through its emphasis on innovation, economic development, and fostering collaboration, the Bluetech program serves as a catalyst for growth, driving forward the marine technology’s ecosystem and positioning İzmir as a prominent hub of entrepreneurial excellence.

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